# The Feasibility of Salinity Control from NRL in the Upper Colorado River Basin

**INTERIM REPORT**

**October 1, 1976**

**US DEPARTMENT OF THE INTERIOR**
**BUREAU OF LAND MANAGEMENT**

Interim Report

# The Feasibility of Salinity Control from National Resource Lands in the Upper Colorado River Basin

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## I. INTRODUCTION

This is an interim report designed to describe, (A) the process used in studying the problem of salinity from diffuse sources on national resource lands (NRL); (B) what is known about the factors affecting salinity from existing research; (C) results of limited investigations on several watersheds important to the Bureau of Land Management (BLM); (D) research presently funded by BLM to answer questions about mechanisms involved in salt movement into the Colorado River; and (E) recommended steps needed to be taken during the coming year and in the future.

The final report, due on October 1, 1977, will recommend alternative technically feasible treatments capable of reducing salinity originating on NRL. It will also include an analysis of the relative costs and benefits incurred by each treatment.

### A. Authority

The BLM salinity control program for the Colorado River Basin has evolved over the past few years as a result of legislative action and interagency agreements.

In 1972, Congress passed Public Law 92-500 which amended the Federal Water Pollution Control Act in terms of restoring and maintaining the chemical integrity of the Nation's waters. Even though the Act did not specifically mention the Colorado River salinity problem, it is generally covered under consideration of chemical pollution and runoff.

On October 30, 1973, the Assistant Secretary for Land and Water Resources (USDI) sent a joint memo to the Bureau of Land Management (BLM) and the Bureau of Reclamation (BR) instructing these Bureaus to "establish a 'working relationship' that will integrate reclamation and public land programs within the Colorado River Basin in such a manner as to expedite the improvement of water quality in the river." The memo further instructed BLM to ". . . assess on-land measures to retain diffuse salt sources in place and if possible, increase the runoff from the public lands through water and land management practices."

On June 24, 1974, the Congress passed Public Law 93-320, Colorado River Basin Salinity Control Act. The Act requires interagency coordination in solving the salinity problem of the Colorado River. It directs the Secretary of the Interior to undertake research and demonstration projects to attain objectives of the Act. Section 203. (a)(1) states that reports on water quality improvement will be required for several river sub-basins; specifically mentioned were Price

River, San Rafael River, Dirty Devil River, McElmo Creek, and Big Sandy River. Reports were to be made by the Secretary of the Interior to the President and Congress on January 1, 1975, and every two years thereafter.

B. Objectives

The objectives of this report were derived from the authorizing documents. Specifically, this report is directed toward presentation of information regarding the feasibility of continuing BLM involvement in the salinity control program. The purpose of this report is not to present site-specific design level feasibility studies.

The specific objectives of the October 1, 1976 report are as follows:

1. Search the literature to determine how much is known about factors resulting in salinity from NRL.

2. Present field data designed to identify diffuse sources of salinity.

3. Describe research needed to identify salt pickup and transport mechanisms.

4. Identify alternative means of reducing salt movement and analyze their effectiveness.

C. Scope

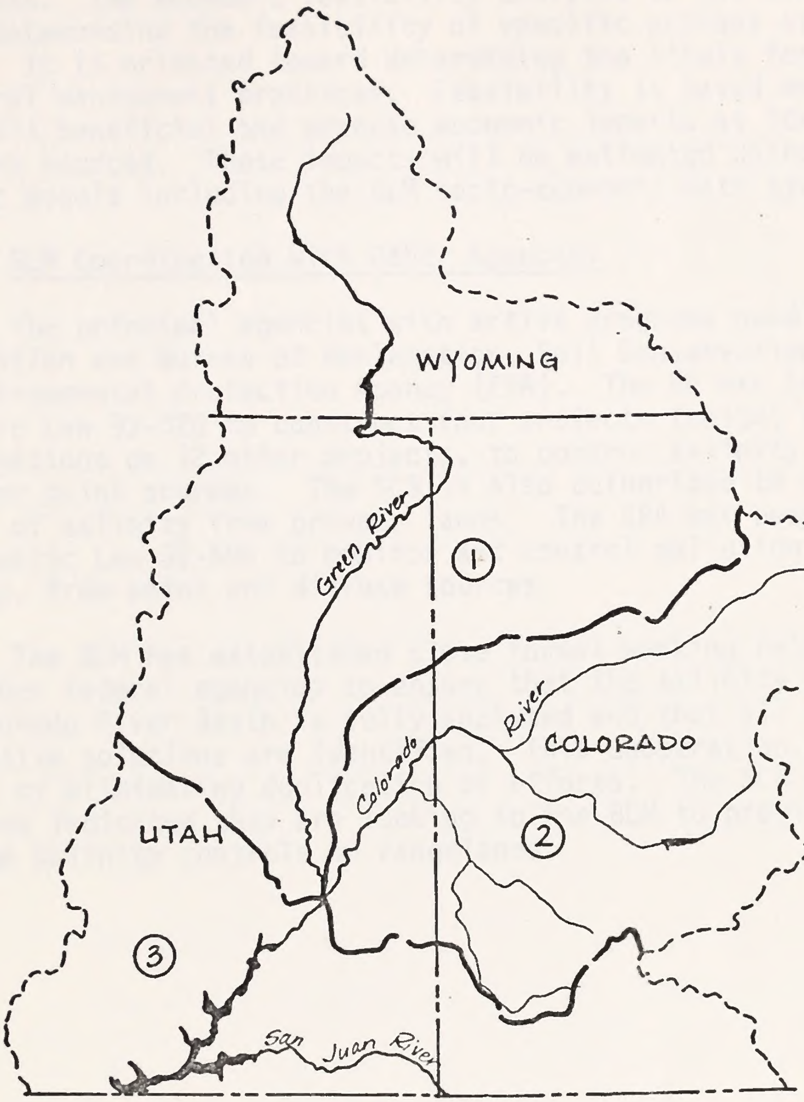
This section delineates the scope of this report in terms of the geographic area covered and the intensity or detail of the analysis.

1. Geographic Area

The authorizing documents clearly indicate that the entire Colorado River Basin including that portion in Mexico is of concern. However, because of financial and manpower limitations, resource investigations of this study have been restricted to the Upper Basin, i.e., that portion of the Basin located within Colorado, Utah and Wyoming, as shown in Figure 1. Economic analyses of corrective actions taken in the Upper Basin will include consideration of benefits derived in the Lower Basin.

2. Intensity of Study

This is a reconnaisance level study. The approach has been to review existing reports of other agencies working on the salinity problem, other secondary data sources, and interagency




UPPER COLORADO RIVER BASIN

HYDROLOGIC SUBREGIONS

① GREEN RIVER

② UPPER MAIN STEM

③ SAN JUAN - COLORADO

Figure 1. Location Map and Hydrologic Subregions

agreements. The economic feasibility analysis is not directed toward determining the feasibility of specific actions at specific places. It is oriented toward determining the likely feasibility of general management practices. Feasibility is based on a comparison of overall beneficial and adverse economic impacts as identified in secondary sources. These impacts will be estimated using existing economic models including the BLM socio-economic data system (SEDS).

## D. BLM Coordination with Other Agencies

The principal agencies with active programs needing BLM coordination are Bureau of Reclamation, Soil Conservation Service (SCS), and Environmental Protection Agency (EPA). The BR has been authorized by Public Law 93-320 to construct four projects (units) and complete investigations on 12 other projects, to control salinity from irrigation and major point sources. The SCS is also authorized to assist in the control of salinity from private lands. The EPA has been authorized under Public Law 92-500 to monitor and control pollution, including salinity, from point and diffuse sources.

The BLM has established close formal working relationships with other federal agencies to ensure that the salinity problem in the Colorado River Basin is fully analyzed and that all reasonable alternative solutions are identified. This cooperation also provides a means of eliminating duplication of efforts. The SCS personnel in Utah have indicated they are looking to the BLM to provide recommendations on salinity controls on rangelands.

## II. BASIN DESCRIPTION

### A. Land Ownership

The Upper Colorado River Basin within Colorado, Utah, and Wyoming comprises a total of 61,595,000 acres. NRL occupy 44 percent of the area, or 27,357,000 acres. State and private lands are often intermingled with NRL, unfenced and all used for similar purposes. The Forest Service administers 21 percent or 13,156,000 acres and other federal agencies control another two percent of the land area or 1,066,000 acres (69).

### B. Uses of NRL

The following is a discussion of the important uses made on national resource lands.

#### 1. Grazing

Grazing of NRL by domestic livestock occurs throughout the Basin. Only a small portion of the grazing lands administered by the BLM are currently being managed under an approved grazing management system. The remainder of NRL is managed on a custodial basis where livestock operators are licensed to graze a set number of animals during a prescribed season each year. In some cases this has resulted in overgrazing. Overgrazing can significantly increase sediment and salinity.

#### 2. Recreation

Use of NRL by off-road vehicles (ORV) has expanded considerably in recent years. This use, which damages vegetation and disturbs the soil, results in accelerated erosion and increased salinity.

#### 3. Mining

Extraction of minerals from NRL can have a significant effect on salinity levels. Disturbance of salt bearing geologic formations not previously exposed to weathering can greatly increase salinity of an entire stream. The BLM leasing procedures must take into account the effects of mining on salt yields and make provisions in leases for control of waste and reclamation of disturbed areas. Some cases may require diverting drainage water from disturbed areas into evaporation ponds in order to control salinity.

## II. [illegible]

### A. [illegible]

[illegible]

### B. [illegible]

The following is a discussion of the important land uses on National Resource Lands.

#### 1. Grazing

[illegible]

#### 2. Recreation

[illegible]

#### 3. Mining

[illegible]

## C. Socio-Economic Setting

Economic characteristics of the Basin are highly diverse. The main population and industrial centers, with economies generally based on export and service activities, are located in the Lower Basin. The structure of the region's economy is primarily based on mineral extraction and processing, agriculture, and outdoor recreation. Large areas of rangeland in the region provide a base for the livestock industry.

### 1. Population

Only one community in the region has a population of more than 20,000, Grand Junction, Colorado. The next largest towns are Durango, Colorado and Rock Springs, Wyoming. About 34 percent of the Upper Basin residents live in urban areas with populations of more than 2,500 inhabitants. Table 1 shows population characteristics and percent change for the Upper Colorado Basin.

### 2. Income and Employment

Table 2 shows earnings for selected economic sectors of counties within the Upper Colorado River Basin. A majority of the earnings in the Upper Basin are attributable to Colorado. This is mainly due to larger marketing centers within the Colorado area of the Basin. The livestock industry, which is dependent on NRL, dominates the agricultural sector throughout the Upper Basin.

Table 3 presents employment data by industrial sector. Agriculture is the major resource based employment sector of the economy. Resource base industries such as petroleum refineries, lumber manufacturing and market-oriented industries such as food processing, printing and publishing account for the bulk of the manufacturing employment in the region.

### 3. Contribution of NRL to Local Economies

Table 4 is a resource industry analysis summary which shows NRL contributions to the Basin's economy. The table shows regional production by resource commodities, regional income, and the significance of BLM's share of production and industry dependency. Livestock forage, recreation and mineral extraction are activities most likely to impact on salinity and, in turn, be impacted by salinity control measures.

#### a. Livestock Forage

Production of livestock forage in the region in 1970 was approximately 10,761,800 AUMs annually with an estimated value of some 602 million dollars, (10). Regional income produced from

Table 1. Population Characteristics, Comparison of Western States and Colorado River Basin, 1970

| Area | Population: Percent of Total: Urban | Rural | Total | % Change 1960-70 |
|---|---|---|---|---|
| Eleven Western States | 83 | 17 | 28,070,978 | 24 |
| Upper Colorado Basin States | 78 | 22 | 3,598,948 | 17 |
| Colorado | 79 | 21 | 2,207,259 | 26 |
| Utah | 80 | 20 | 1,059,273 | 19 |
| Wyoming | 60 | 40 | 332,416 | 1 |
| Upper Colorado River Basin 1/ | 34 | 66 | 292,566 | 3 |
| Colorado | 34 | 66 | 189,892 | 8 |
| Utah | 23 | 77 | 64,788 | -8 |
| Wyoming | 54 | 46 | 37,886 | -1 |

Source: BLM-Socio-Economic Data System (SEDS) and 1970 Census of Population.

1/ Approximated by County Boundaries

Table 2. Earnings by Industrial Sector, 1970

| Industrial Sector | Earnings ($1000) | | | |
|---|---|---|---|---|
| | Colorado | Utah | Wyoming | Total Upper Basin |
| Agriculture | | | | |
| Livestock | 27,019 | 5,335 | 14,413 | 46,668 |
| Other | 20,135 | 1,487 | 1,211 | 22,833 |
| Mining | | | | |
| Metals | 18,452 | 3,879 | 11,762 | 34,093 |
| Fossil Fuels | 10,688 | 13,172 | 14,794 | 38,654 |
| Quarrying | 3,911 | 2,853 | 2,303 | 9,067 |
| Contract Construction | 41,433 | 9,082 | 8,664 | 59,179 |
| Manufacturing | | | | |
| Food and Kindred Products | 4,821 | 921 | 861 | 6,603 |
| Lumber & Wood Products | 8,453 | 1,501 | 1,012 | 10,966 |
| Other Manufacturing | 14,377 | 3,936 | 7,305 | 25,618 |
| Transportation and Communication | 19,814 | 6,305 | 15,438 | 41,557 |
| Public Utilities | 15,391 | 2,463 | 2,532 | 20,386 |
| Wholesale & Retail | 69,982 | 15,797 | 17,609 | 103,388 |
| Fin., Ins., & Real Estate | 14,149 | 2,066 | 2,501 | 18,716 |
| Services | 72,355 | 12,934 | 17,374 | 102,663 |
| Government | | | | |
| Federal | 26,858 | 10,660 | 7,578 | 45,096 |
| State/Local | 34,802 | 14,506 | 11,783 | 61,091 |
| Total | 422,640 | 106,627 | 137,041 | 666,306 |

Source: BLM-SEDS

Table 3. Employment in the Upper Colorado River Basin, by Industrial Sector, 1970.

| Industrial Sector | Colorado | Utah | Wyoming | Total Upper Basin |
|---|---|---|---|---|
| Agriculture (Farm) | 7,385 | 2,004 | 1,429 | 10,818 |
| Government (Federal, Civilian, Military, State) | 3,866 | 1,676 | 613 | 6,175 |
| Manufacturing | 4,377 | 1,217 | 986 | 6,580 |
| Mining | 3,975 | 2,926 | 1,846 | 8,747 |
| Construction | 6,118 | 1,721 | 1,001 | 8,840 |
| Transportation/ Communication | 3,179 | 931 | 1,239 | 5,349 |
| Wholesale-retail trade | 14,682 | 3,857 | 2,638 | 21,177 |
| Fin., Ins., and Real Estate | 2,516 | 406 | 283 | 3,205 |
| Services and Other | 13,154 | 2,619 | 2,293 | 18,066 |
| All Industry | 51,222 | 20,546 | 14,008 | 85,776 |

Source: BLM-SEDS

Table 4. Resource Industry Analysis Summary (10)

| Resource Industry | Regional Production | Value ($000) | Reg'l Income ($000) | Amt. Produced | Reg'l Industry Dependency |
|---|---|---|---|---|---|
| Upper Colorado River Basin | | | | NRL Contribution | |
| **Minerals:** | | | | | |
| Energy (Coal) | 17,981 2/ S. Tons | 169,000 | 24,352 | 12,000 S. Tons | 67% |
| Petroleum Products | 67,118 2/ bbls | 332,652 | 14,302 | 49,251 bbls | 73% |
| Quarry Products (Sands & Gravel) | 9,661 S. Tons | 10,933 | 11,583 | 9,071 S. Tons | 94% |
| Metal Mining | | 322,900 | 34,093 | $150,308 | 47% |
| Forest Products | 47,367 mbf | 16,720 | 10,966 | 3,316 mbf | 7% |
| Livestock Forage | 10,761,831 aum's | 602,190 | 46,668 | 1,469,801 aum's | 14% |
| **Wildlife:** | | | | | |
| Hunting & Fishing | 91,470,500 2/ @ $7.00 | 640,203.5 | 104,423 | 7,317,640 V.D. | 7% |
| **Recreation:** | | | | | |
| General Outdoor Recreation 1/ | 36,256,972 2/ @ $3.00 | 108,770.9 3/ | 7,251 | 2,900,558 V.D. | 8% |

1/ Includes major ski areas
2/ Comprehensive Framework Studies, Upper Colorado Basin, 1971
3/ Expenditures.

livestock was in excess of 46 million dollars. BLM administered lands supplied only 14 percent of the total forage consumed. However, forage from NRL is provided during a period of the year when forage from ranch, or other private lands, is not available, or if available would be at a higher cost. Therefore, NRL produced forage can be critical to the local livestock industry.

b. Recreation

Hunting, fishing and general recreation use data imposes a constraint on analysis of contribution of NRL to local economies. There is no consistent information on use of BLM administered lands. Therefore, the analysis is based on estimates of visitor-days and recreation expenditures.

c. Minerals

The Upper Colorado Region is underlain by approximately 139 billion tons of coal of which about one-half is assumed to be recoverable, (67). About 55 percent is located in the Green River Subregion or the eastern Utah and southwest Wyoming sections. A substantial part of the total coal resource is found less than 1,000 feet below the surface and is recoverable by strip and other mining methods. In 1971, coal production was estimated for the region to be slightly in excess of 17,981,000 short tons and produced a regional income of slightly more than 24 million dollars annually. Two-thirds of the coal mined within the region came from NRL. The regional income effect from this resource was in excess of 24 million dollars.

Quarry products are primarily sand and gravel, building stone, as well as some clay products. BLM administered lands account for about 94 percent of the quarry products within the region. Of 9,661,000 short tons produced in 1973, 9,071,000 short tons of quarry products were produced on NRL.

D. Climate

Weather patterns and resulting precipitation in the Upper Basin are associated with two general weather systems, one operating during the winter, the other during the summer. Winter storms are the result of moist Pacific air associated with frontal systems moving eastward across the Basin. Orographic lifting is an important factor in causing precipitation because of the large number of mountains within the Basin. The Upper Basin is on the lee side of the Wasatch mountain range and Wasatch Plateau. As air descends over this high range it warms and dries out resulting in a decreased precipitation (37). Storms cover relatively broad areas.

The principal source of summer precipitation is the northerly flow of warm moist air originating in the Gulf of Mexico. Precipitation during the summer comes as high intensity thunderstorms which cover a limited area. Rainfall amounts are extremely variable and can be very high, causing damage to soils.

Various publications place the range in precipitation over the Basin from 4 to 40 inches or greater. Weather Bureau data from stations important to NRL indicate a range from 5 to 17 inches. Temperature varies greatly throughout the Upper Basin and is dependent upon elevation and latitude. Winter minimum and summer maximum temperatures can be severe. Daily temperatures, from the daytime high to the nighttime low, can vary as much as 40 degrees Fahrenheit (F). The number of frost-free days or consecutive days with a minimum temperature above 32$^{o}$ F., increases as elevation decreases. Winds in the Basin are moderate to high. Wind velocity recorded at Grand Junction, Colorado has exceeded 50 mph in every month of the year, (68).

### E. Topography

The Upper Colorado River Basin consists of broad plateaus, steep mountains, rolling hills, rough canyon lands, and gently sloping valleys. The area around Canyon Lands National Park near the confluence of the Green and Colorado Rivers is characterized by extremely steep escarpments ranging from 1,000 to 1,400 feet in height. To the northwest is the San Rafael Desert, made up of active and stable sand dunes ranging from 4,900 to 9,200 feet.

The San Rafael Swell situated northwest of the dunes and west of Green River, Utah, is a large kidney shaped arch of stratified rock with the layers bent downward away from the crest approximately 15 miles wide and 42 miles long. Elevations of the swell rise from a base level of 5,000 feet on the southwest to 7,900 feet at the peak. To the northeast of the swell, the Book Cliffs rise above the Mancos shale forming a series of exposed tilted sedimentary rocks. The Book Cliffs have an abrupt increase in elevation ranging from 6,000 to 9,000 feet within a distance of 6 to 15 miles. They then grade into the Roan Cliffs immediately to the north.

The Travaputs Plateau northeast of Price, Utah, dips to the north decreasing in elevation to 5,200 feet, with draws and river bottoms at elevations of 4,700 feet. Here the sedimentary cap rock grades into fluvial and lake deposits. The valleys contain relatively younger alluvial deposits associated with active streams. The Uinta Mountains to the north of Vernal are a series of dipping strata with the cap rock sloping downward to the north. They form a mountain range of peaks and valleys gradually increasing in elevation from 5,200 to 9,200 feet within a distance of 15 miles.

The Colorado River Basin is bordered on the west by the Wasatch Plateau ranging from 5,500 feet in Castle Valley, Utah, to 10,000 at the Continental Divide and on the east by the Rocky Mountains. The numerous plateaus within the Basin reach elevations from 8,000 to 10,000 feet.

The eastern portion of the Upper Basin in Colorado is a series of alternating valleys and plateaus from the south to the north, each oriented from the northwest to the southeast. The Uncompahgre and Roan Plateaus are the major mountainous features west of the Continental Divide. Major valleys between these plateaus are Gypsum, Paradox and Grand Valleys. The Piceance and Axial Basins to the north are dissected by lower hills and canyons. The Axial valley is the result of an extensive uplift which shattered the overlying sedimentary rocks. Erosion of the fractured material has left a low lying valley of rolling hills in Mancos shale, surrounded by cliffs and plateaus of the original overburden.

The northern tip of the Colorado River Basin in Wyoming is comprised of steep mountain slopes and broad, high elevation plains that range from 6,400 to 7,400 feet with an estimated average elevation of 6,800 feet. The northeastern edge of the basin is occupied by the Red Desert. It is an extensive closed basin with many areas of saline slicks and marching sand dunes over the red clay. The area to the east of the Red Desert and north of the Boars Tusk (a residual volcanic neck) is a large active sand dune field approximately 100 miles long and 20 miles wide. The dunes range from 20 to 50 feet high with many blowouts down to the water table.

## F. Basin Hydrology

### 1. Hydrologic Setting

The Upper Colorado River Basin is divided into three major subregions as shown in Figure 1. The Colorado Mainstem Subregion consists of a small part of west-central Utah and a large area of west-central Colorado above its confluence with the Green River. The Green River Subregion consists of the Green River and its tributaries. It drains northeastern Utah, northwestern Colorado and southwestern Wyoming. The San Juan Subregion contains the Colorado River from the compact point at Lee Ferry, Arizona, to its confluence with the Green River. It consists primarily of southeastern Utah and southwestern Colorado.

The hydrologic setting of the Colorado River Basin ranges from relatively low lying arid desert lands that yield relatively little flow to steep, high mountains which contribute the major streamflow of the Colorado River. The runoff contribution of the arid desert area is generally from high intensity spring and summer thunderstorms. They typically yield small amounts of water per year, usually less than 50 acre feet per square mile.

The Colorado River Basin is bordered on the west by the Wasatch Plateau ranging from 5,000 feet in Castle Valley, Utah, to 10,000 on the Continental Divide and on the east by the Rocky Mountains. [illegible] elevation within the basin range elevations from 4,000 to 10,000 feet.

The eastern portion of the Upper Basin in Colorado is a series of alternating plateaus and mesas [illegible] from the basin to the north, south, [illegible] from the northwest to the southeast. The Uncompahgre [illegible] Plateaus are the major [illegible] features west of the Continental Divide. Major valleys between these plateaus are Gunnison, Paradox and Grand Valleys. The Piceance and White Basins to the north are dissected by deep gulches and canyons. The Uinta Basin is the result of an extensive uplift which distorted the overlying sedimentary rocks. Erosion of the Uncompahgre upwarp has left a few large valleys of [illegible] surrounded by cliffs and plateaus of the [illegible] sedimentaries.

The southern tip of the Colorado River Basin in Wyoming is comprised of steep mountain slopes and broad, high elevation plains that range from 6,500 to 7,000 feet with an occasional maximum elevation of 8,000 feet. The northwestern edge of the basin is occupied by the Red Desert. It is an extensive [illegible] with many areas of [illegible] and [illegible] land areas near the red [illegible]. The area of the east of the Red Desert and north of the Great Divide Basin is [illegible] of a [illegible] sand dune field approximately 100 miles long and several miles wide. The dunes range from 20 to 70 feet high with sand blowouts down to the water table.

F. Basin Hydrology

1. Hydrologic Setting

The Upper Colorado River Basin is divided into three major watersheds as shown in Figure [illegible]. The Colorado Mainstem [illegible] region consists of a small part of north-eastern Utah and a large area of west-central Colorado above the [illegible] confluence. The Green River Subregion consists of the upper Green and its tributaries. It drains northwestern Utah, northeastern Colorado and southwestern Wyoming. The San Juan Subregion includes the Colorado River from the [illegible] point of the Green [illegible] to its confluence with the Green River. It consists of southeastern Utah, northwestern New Mexico and southwestern Colorado.

The hydrologic setting of the Colorado River Basin ranges from relatively low lying arid [illegible] relatively little flow of water, with [illegible] the major [illegible] of the Colorado River [illegible] arid desert area is generally [illegible] thunderstorms. [illegible]

The mountainous watersheds produce the major perennial streams of the Colorado River Basin. The flow of these streams can be divided into two parts: (a) base flow and (b) high runoff. The base flow or low flow period is contributed from groundwater and generally occurs from August through March. The discharge during this time is relatively uniform, when compared with the high flow period.

The high runoff period generally occurs during the period of April through July and is caused primarily by melting of the mountain snowpack and occurs during May and June with April and July being transitional months. The April runoff is generally from low elevation snowmelt and may provide a separate discharge peak in the hydrograph. The timing and amount of runoff for a basin varies depending on elevation, location and yearly climatic conditions.

Water quality will vary depending on stream geology and the effects of man. Natural stream flow and water quality is modified through transmountain diversions, municipal and industrial uses, agricultural, energy, power generation, and storage projects.

2. Water Allocation

The water of the Colorado River is allocated between the Basin states by the Colorado River Compact of 1922. The physical division between the Upper and Lower Basin is Lee Ferry, Arizona. The compact divided the water between the Upper and Lower Basin states and guaranteed the Lower Basin a total of 75 million acre feet in any consecutive 10 year period plus 750,000 acre feet allocated to Mexico in the Mexican treaty (1944). The compact water division is based on a period of high runoff, which results in an Upper Basin yield of approximately 6.5 million acre feet annually, estimated by the BR (13).

Water available to the Upper Basin states was divided by the Upper Colorado River Compact. It provided for delivery of 50,000 acre feet to Arizona (Upper Basin allocation) and the remaining water divided between Colorado, Utah, Wyoming and New Mexico with 51.75, 23.0, 14.0 and 11.25 percent, respectively (70).

## III. PRESENT CONDITIONS

### A. Geology

#### 1. Geomorphic History

Deposition of the basin geologic units occurred almost continuously from Mississipian to Tertiary time. The landscape consisted of shallow seas and plains which were often actively depositing marine shales and sandstones containing vast quantities of evaporites (51).

During the middle of Tertiary time the entire landscape underwent sharp uplifts and deformations. Streams began carving their way downward through the soft shales and sandstones. In those areas where more resistant cap rocks occurred, the rivers cut deep, sharp, cliffed ravines into the underlying rocks. The softer surface rocks, such as the Mancos shale, were weathered into broad plains of rolling hills typical of the Axial Valley and Coal Oil Basin in Colorado.

A series of synclines (valleys or depressions with inward dipping sedimentary rocks) were created from the collapse and erosion of salt domes within the Paradox Salt Embayment covering all of southeastern Utah, southwestern Colorado, northwestern corner of New Mexico, and part of the northeastern corner of Arizona. Although the Paradox is extensive it is buried deep within the geologic profile, occurring within the Hermosa Formation of Pennsylvanian time. The Paradox consists mainly of halite (salt) and anhydrite beds with some dolomite. When found near the surface it is strongly detrimental to water quality. However, it outcrops at only a few locations, such as the Paradox Valley along the Dolores River.

The Paradox has had a strong influence on the surface geomorphology. A series of synclines occur in roughly three parallel belts beginning at the base of the Book Cliffs near the Green River in Utah, and extends to the southeast for nearly 100 miles. Each syncline is several miles long and about a mile wide, surrounded by cliffs of more resistant rocks. They were all caused by the solution and collapse of salt beds within the Paradox Formation. Other significant synclines are Castle Valley, Utah and Sinbad Valley, Paradox Valley and Gypsum Valley in Colorado.

Another major salt bearing formation is the Mancos shale. The Mancos stratigraphically overlies the Dakota sandstone and was deposited during Cretaceous time. It is a nearly homogeneous, drab, bluish gray shale with thin beds of gray to brown sandstone and yellowish sandy shale. The Mancos consists of well bedded calcareous shales and mudstones with some silty to coarse limestone.

Mancos shale can also be subdivided into the Masuk, Blue Gate, and Tununk shale members, each having a slightly different chemical composition. Differentiation of each member can only be done when stratigraphically separated by other Cretaceous Rock members. The lower part of the Mancos weathers to a light gray or white color due to the high percentage of carbonates. The gray to black shales overlying the calcareous zone range from 1,500 to 1,700 feet thick and weathers into a light gray mantle. The upper beds, 1,200 to 1,500 feet thick, are generally fossiliferous and contain sandy shales, calcareous sandstones and concreations. These beds grade into the Mesa Verde Group stratigraphically overlying it. Primary zones of gradation into the sandstone are the Buck and Anchor Mine Tongues of the Mancos shale.

Pennsylvanian and Permian rocks are also comprised of marine carbonates, evaporites, shale and sandstone with maximum thicknesses of 15,000 feet. The Wasatch and Green River Formations of Tertiary time are also extensive salt producers, particularly in the southwestern corner of Wyoming. A summary of the major geologic formations within several of the more prominent sub-basins is given in Table 5.

## 2. Geological Relationships to Water Quality

Rock formations within the Upper Colorado River Basin consist primarily of bedded marine and lacustrine rocks. Water movement through and over these formations produces salt loads of varying quantities depending on the availability of salt permeability, and presence of groundwater within the formation.

The headwater areas of the Upper Colorado River Basin (Alpine and Pine-fir Forests) are generally made up of metamorphic, igneous, granitic, and indurated sedimentary rocks. These rocks are low in soluble salts and generally yield water with salt concentrations of less than 100 milligrams per liter (mg/l), containing primarily calcium bicarbonate. These areas are shown as Precambrian plutonic and metamorphic rocks in Figure 2, and form nonsaline soils. The Precambrian sedimentary and Tertiary volcanic rocks are also nonsaline.

Table 5. Distribution of Geologic Formations According to Basin (49)

| Subbasin Name | Geologic Characteristics Geologic Type a/ (% of Total Subbasin) | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
| Green River above Fontenelle Reservoir | 15 | 50 | 10 | 10 | 5 | 10 | | |
| Big Sandy Creek Basin | 10 | 85 | | | | | | 5 |
| Green River above Flaming Gorge Dam | 5 | 55 | 2 | 3 | | 5 | | 30 |
| Little Snake River Basin | 10 | 60 | 20 | | | | 2 | 8 |
| Ashley Creek Basin | 5 | 10 | 40 | 10 | 5 | 10 | | 20 |
| Duchesne River above Randlett, Utah | 5 | 55 | | | 5 | 10 | | 25 |
| White River Basin | 5 | 50 | 20 | 3 | 2 | 10 | 10 | |
| Price River Basin | 10 | 5 | 60 | 25 | | | | |
| San Rafael River Basin, Green River, Ut. | 5 | 15 | 25 | 25 | 20 | 10 | | |
| Eagle River Basin | | | 20 | | | 45 | 10 | 25 |
| Roaring Fork River Basin | 5 | | 15 | | | 30 | 25 | 25 |
| Plateau Creek Basin | | 80 | 10 | | | | 10 | |
| Uncompahgre River Basin | 10 | | 30 | 30 | | | 25 | 5 |
| Dolores River Basin | 5 | | 35 | 40 | | 5 | 10 | 5 |
| Colorado River above Cisco, Utah | | 5 | 30 | 45 | | 10 | | 10 |
| San Juan River above Bluff, Utah | 3 | 6 | 10 | 40 | 25 | 15 | 1 | |
| Colorado River above Lee's Ferry, Ariz. | | | 25 | 45 | 5 | 15 | 10 | |

a/ Description of geological classifications used:

(1) Unconsolidated continental deposits: Fluvial and glacial fluvial deposits beneath and bordering streams terraces. Includes pediment gravels and sand dunes.

(2) Continental rocks: Lacustrine deposits of shale, siltstone, fire-grained sandstone. Includes the Wasatch, Green River, Uintah and Bridger formations.

(3) Continental and marine rocks: Shale and sandstone. Includes the Mancos, Mesa Verde, and related formations.

(4) Predominantly continental rock: Massive quartzose sandstone, inter-bedded sandstone and mudstone, and conglomerate. Includes Glen Canyon, San Rafael groups, Morrison and Dakota formations.

(5) Continental and marine rocks: Mudstone, siltstone and shale, conglomerate. Includes Moenkopi and Chinle formations.

(6) Marine rocks: Limestone, quartzite, shale, and evaporites with quartzose sandstone. Includes the Leadville, Hermosa, Cutler, Weber and related formations.

(7) Igneous rocks: Volcanic and intrusive basalt, andesite, diorite, and others. Includes lava flows and related ejectamenta and intrusive laccoliths.

(8) Igneous and metamorphic rocks: Schist, granite greiss, granite, and granite permatite. Forms the basement complex upon which Units 1 to 7 rest.

LEGEND

| | |
|---|---|
| 1 | Tertiary continental and Quaternary deposits including the Green River and Wasatch Formations. |
| 2 | Lower tertiary volcanic rocks. |
| 3 | Eocene continental deposits. |
| 4 | Eocene lacustrine deposits. |
| 5 | Upper Cretaceous marine deposits including the Mancos shale and Price River Formation. |
| 6 | Cretaceous marine deposits including the Colorado group. |
| 7 | Lower Jurassic marine deposits - Glen Canyon group. |
| 8 | Jurassic marine-continental deposits including the Morrison Formation and San Rafael group. |
| 9 | Triassic marine deposits - Moenkopi and Chinle Formations. |
| 10 | Permian marine deposits. |
| 11 | Pennsylvanian marine deposits - Hermosa and Paradox Formations. |
| 12 | Paleocene continental deposits. |
| 13 | Precambrian plutonic and metamorphic rocks. |
| 14 | Precambrian sedimentary and tertiary volcanic rocks. |

Figure 2. General Geology of the Upper Colorado River Basin

Adapted from the USGS Geologic Map of the United States

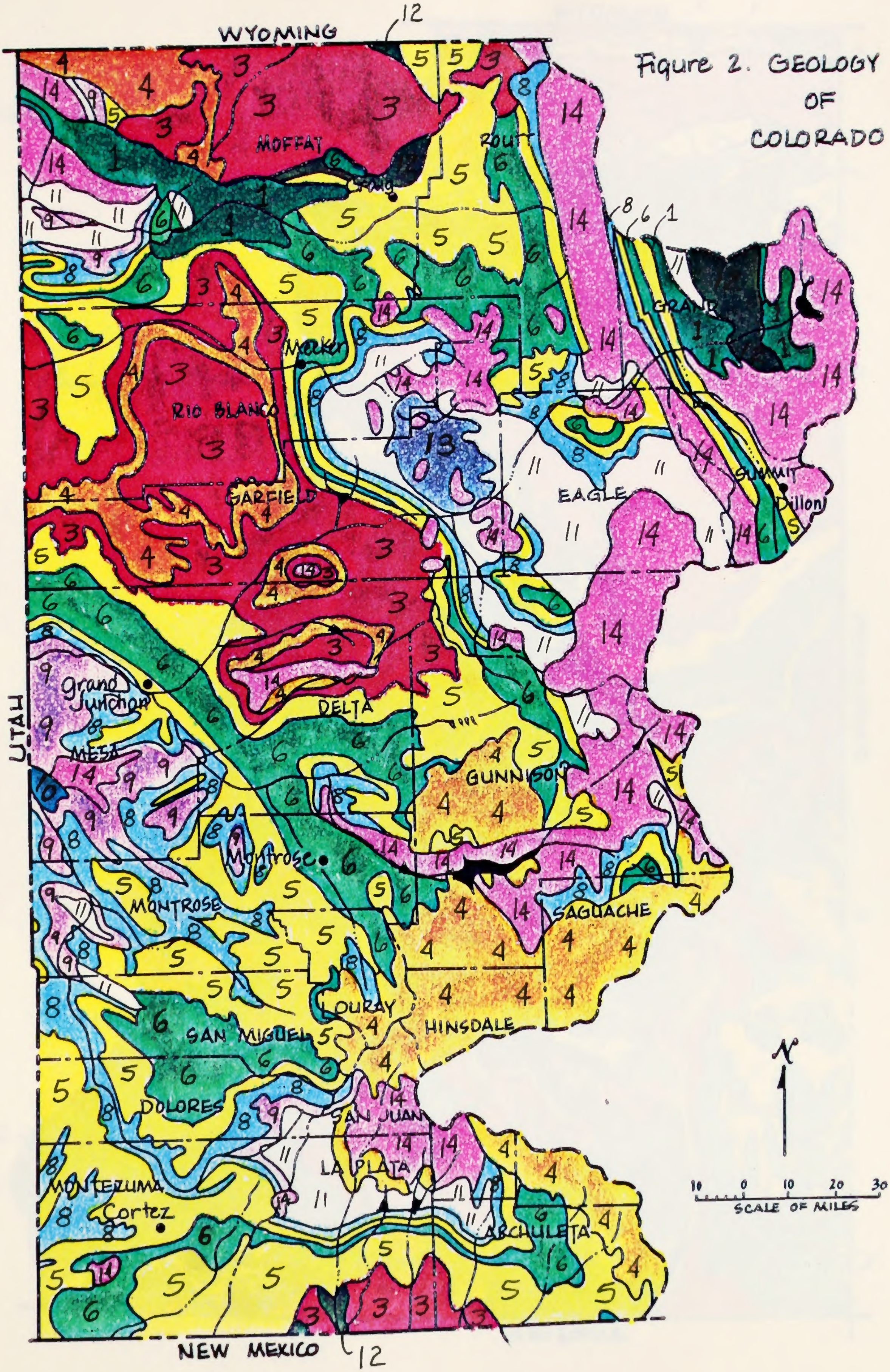
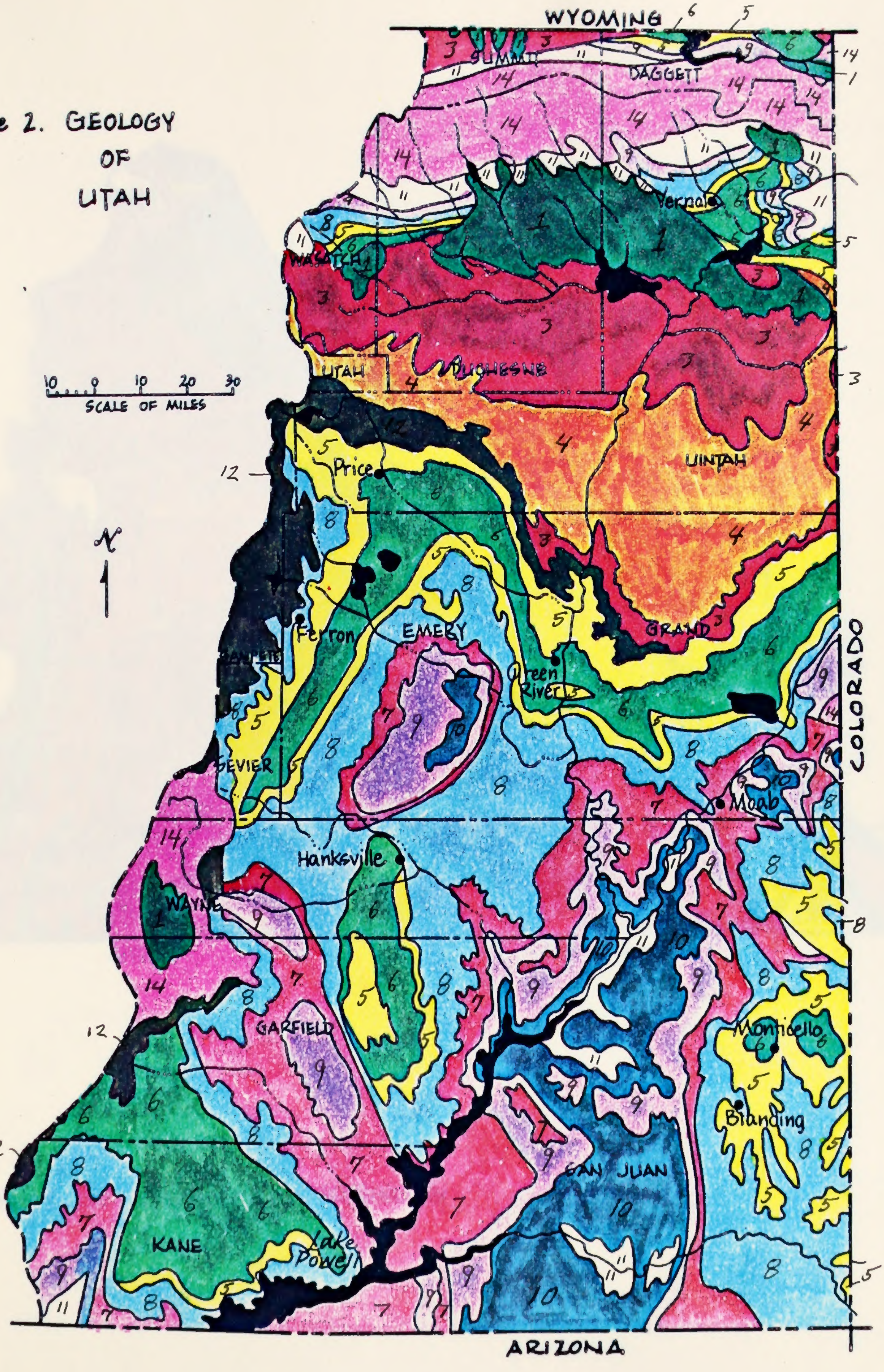



Figure 2. GEOLOGY OF COLORADO

Figure 2. GEOLOGY OF UTAH



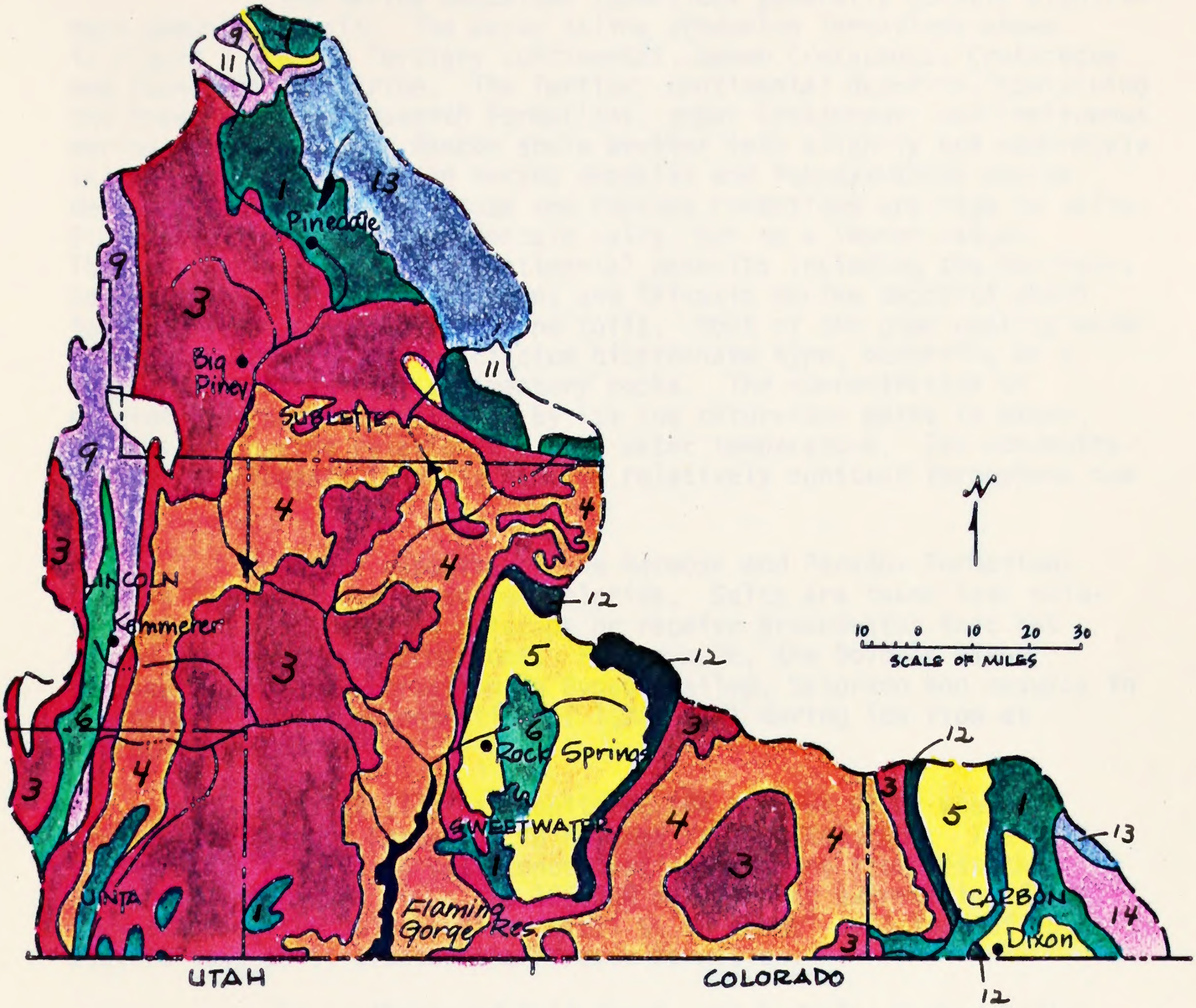



Figure 2. GEOLOGY OF WYOMING

The marine deposited formations generally contain significant amounts of salt. The major saline producing formations shown in Figure 2 are the Tertiary continental, upper Cretaceous, Cretaceous and Pennsylvanian marine. The Tertiary continental deposits, containing the Green River and Wasatch Formations, upper Cretaceous, and Cretaceous marine deposits of the Mancos shale weather into slightly and moderately saline soils. The Permian marine deposits and Pennsylvanian marine deposits including the Hermosa and Paradox Formations are high in salts. Other marine deposits also contain salts, but to a lesser extent. They are Jurassic marine - continental deposits including the Morrison, San Rafael and Glen Canyon groups and Triassic marine deposits which form nonsaline to slightly saline soils. Most of the good quality water from these areas is of the calcium bicarbonate type, occurring as a cementing agent in many sedimentary rocks. The concentration of calcium bicarbonate is limited by its low saturation point in water, and has an inverse relationship with water temperature. The concentration of bicarbonate in soils remains relatively constant throughout the basin.

Marine deposits of the Hermosa and Paradox Formations contain large amounts of sodium-chloride. Salts are taken into solution as the streams cross outcrops or receive groundwater that has passed through these formations. For example, the Dolores River crosses the Paradox Formation in Gypsum Valley, Colorado and results in a sodium chloride concentration of 1,200 mg/l during low flow at Bedrock, Colorado.

The BR (14) has monitored the Dolores River where it crosses the Paradox Formation in Paradox Valley, Colorado. The brine contribution results in salt concentrations ranging from less than 200 mg/l during high flows, to 166,000 mg/l during extreme low flows. They estimate the Dolores River picks up an annual salt load of about 200,000 tons as it crosses the Paradox Formation.

The salinity of Salt Creek, which drains Sinbad Valley, is extremely high. Electrical conductivity (E.C.) measurements of 37,000, 44,000, and 51,300 μmhos/cm were recorded in 1951, 1952, and 1976, respectively. Much of this is sodium chloride (39).

The Mancos Formation is another marine deposited shale which has a significant impact on salinity of the Colorado River. The Mancos shale is a deposition of saline muds in a shallow sea environment. Sea recessions and evaporation caused the precipitation of sulfates and carbonates within the mud while carbonates acted as a cementing agent to form shales.

The marine Cretaceous formations generally contain signifi- cant amounts of salt. The major saline-producing formations [illegible] in Figure [illegible] are the Tertiary continental. [illegible]

[illegible] Colorado.

[illegible] 700,000 tons [illegible]

The salinity of [illegible] is extremely high. [illegible] 1970, [illegible]

The [illegible] which has a significant [illegible] a concentrated [illegible]

The Mancos shale in Grand Valley is very thinly bedded and firm to hard. The entire rock is calcareous and has local concentrations of gypsum. Weathered shale is thinly bedded and forms a clay loam textured soil weathering to a lithic contact at a depth of 5 to 20 feet. Gypsum occurs in the Mancos shale as single crystals or discontinuous seams approximately a quarter inch in width, occurring along the shale bedding planes and joints. Intermixed grains and crystals of gypsum occur throughout the matrix of the shale.

The Mancos shale has distinct hydrologic characteristics. The shale itself is highly impermeable and yields only small quantities of saline waters. However, the weathered zone above the undisturbed Mancos has been found to contain moisture. The BR found a particularly high water-bearing zone at the contact between two geologic formations. Several holes drilled by Schneider (57) had artesian water within the weathered shale, particularly in the Little Salt Wash-Abode Wash area in Colorado. This water bearing zone is particulary thin and rarely reaches a thickness of more than 6 inches and occurs at a depth of 5 to 18 feet.

Artesian pressure indicates the water bearing zone is confined. The zones immediately above and below this water bearing layer are moisture deficient, showing little evidence of capillary rise. The artesian pressure brings the static water level up between two and nine feet above the interflow zone.

Runoff from Mancos shale generally becomes saturated with gypsum at about 2,500 µmhos/cm as found by Whitmore (71). Interaction with other ions such as sodium and chloride increases this solubility, but the major impact on total dissolved solids is through the pick up of additional ions separate from gypsum. Data collected during this study indicates surface runoff from Mancos areas would generally have concentrations below 2,500 mg/1 and are tied in very closely with the salinity of the leached surface soil.

Groundwater from Mancos areas has concentrations up to 6,000 mg/1, of primarily calcium, sodium, and sulfate ions. This is due to the longer contact time and availability of salts in the unleached layers.

Other formations that yield salt to the Colorado River are the Mesa Verde, Wasatch and Green River Formations. They contain areas of high salt content and are highly erosive. The Green River drainage of Wyoming has large areas of the Wasatch and Green River Formations. Concentration of salts in water from this area is further increased by the activities of man in the form of irrigation and other withdrawals of good quality water.

## B. Soils

The BR (15) has grouped the soils of the Upper Colorado River Basin into four salinity classes, as shown in Figure 3. They are non-saline, slightly saline, moderately saline, and strongly saline. The moderately and strongly saline soils have the greatest potential for salt contribution to the Colorado River. The strongly saline soils have an E.C. greater than 16,000 µmhos/cm throughout the soil profile. There are 103,000 acres of strongly saline soils, all of which occur in Utah. A total of 28,000 acres are situated on NRL, 58,000 acres are located within the Uinta Basin, and 18,000 are on private land near Huntington and Cleveland, Utah (see Figure 3 for Utah). These soils are situated in poorly drained bottom lands. Sager's Wash, near Cisco, Utah, contains another tract of strongly saline soils consisting of 24,000 acres of highly erodible desert soils occurring in lower alluvial flood plains. Another 3,000 acre tract lies in the upper Paria River area near Tropic, Utah. Ownership is both NRL and private.

Moderately saline soils are much more extensive in the Upper Colorado River drainage. These soils have an E.C. of 4,000 to 16,000 µmhos/cm above 20 inches in depth and greater than 16,000 µmhos/cm below 20 inches. A total of 2,204,000 acres are classified as moderately saline. Approximately half of this acreage is situated on NRL. These lands are the most prominent contributors of diffuse sources of salts within the Colorado River, particularly when irrigated. Approximately 40 percent, or 915,000 acres of the moderately and strongly saline lands are found in Utah. The Uinta Basin contains 239,000 acres of these soils located primarily along the Duchesne, White and Green Rivers. They also occur in the fine textured, poorly drained lower bottom lands under irrigation in the vicinity of Myton, Roosevelt and Jensen, Utah. These areas are primarily Indian and private lands with very little NRL.

The area east of the Wasatch Mountains and south of Book Cliffs in Carbon, Emery, and Grand Counties, Utah, and the area along the Fremont River contains approximately 430,000 acres of moderately saline soils. Saline soils are found in Utah from Emery to Price, Green River, Cisco, and the area along the state line west of Mack, Colorado. Most of this salinity is associated with Mancos shale and receives less than six inches annual precipitation.

Most of the moderately saline soils totaling 743,000 acres within western Colorado are associated with low lying flood plains surrounding the major streams draining from the Mancos shale, Lewis shale and some members of the Wasatch Formation. The largest areas of moderately saline soils occur in the Grand and Uncompahgre Valleys. Smaller areas occur along the White River near Rangely; the Mancos

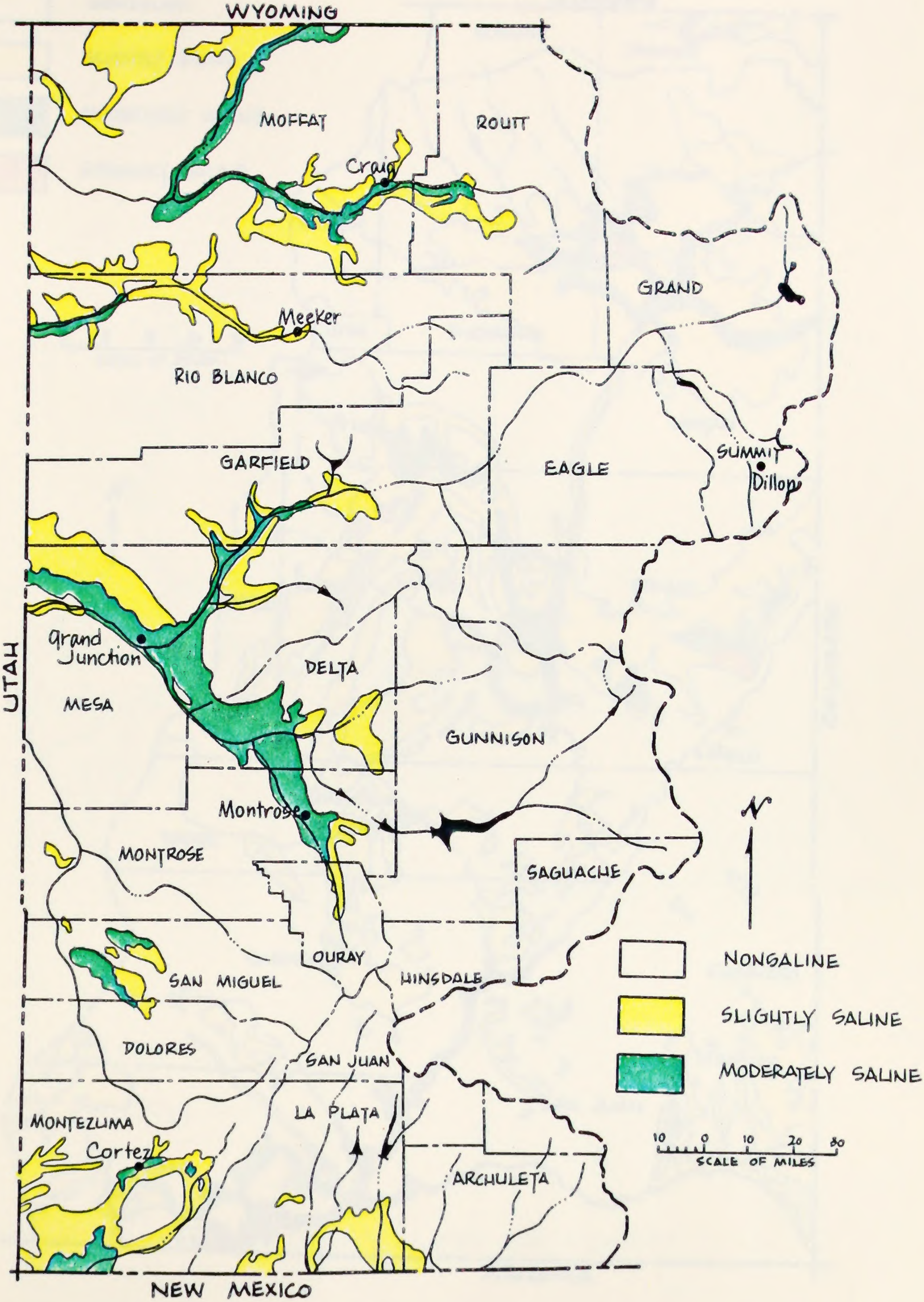



Figure 3. GENERAL SOIL SALINITY CLASSES FOR COLORADO

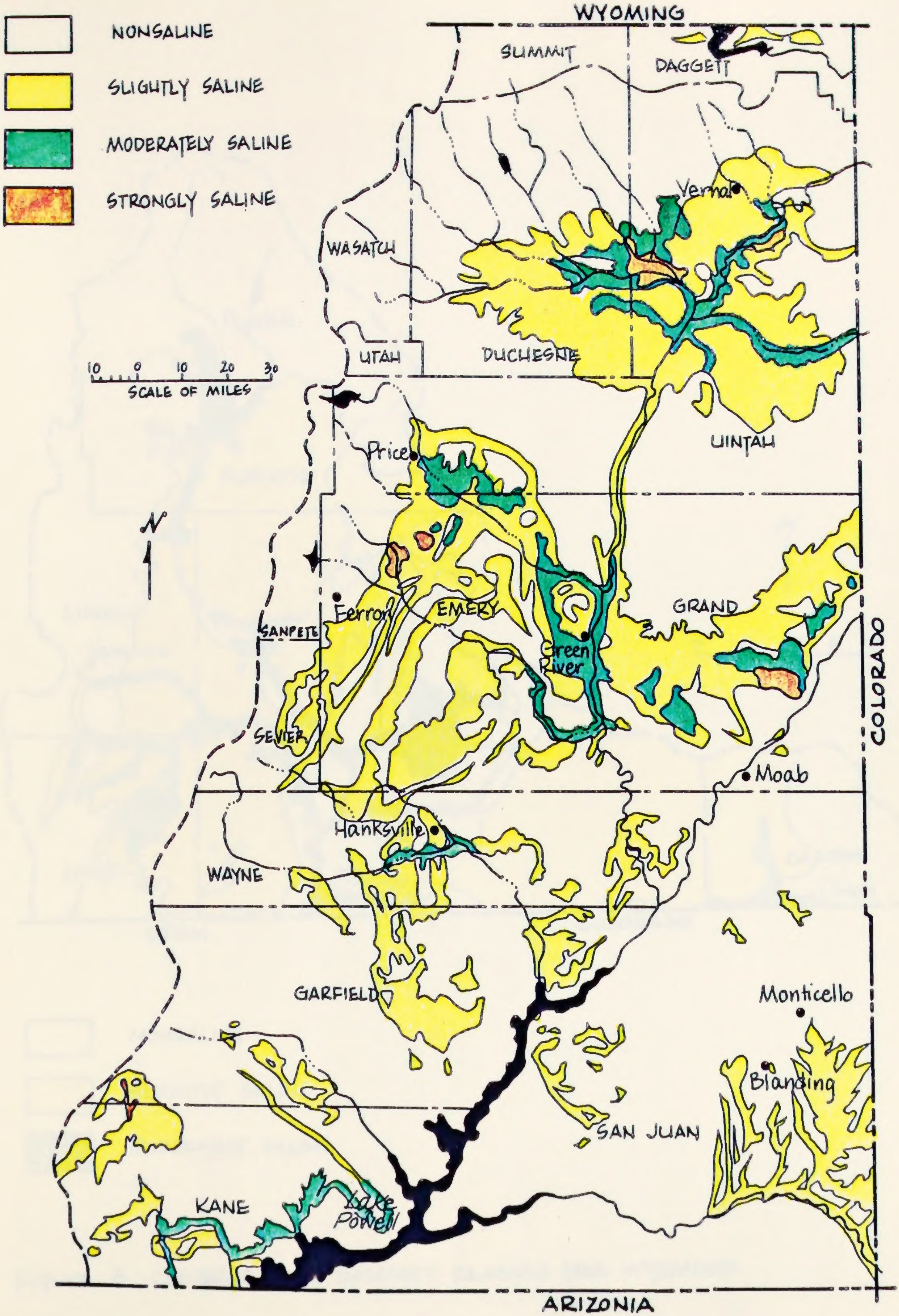



Figure 3. GENERAL SOIL SALINITY CLASSES FOR UTAH

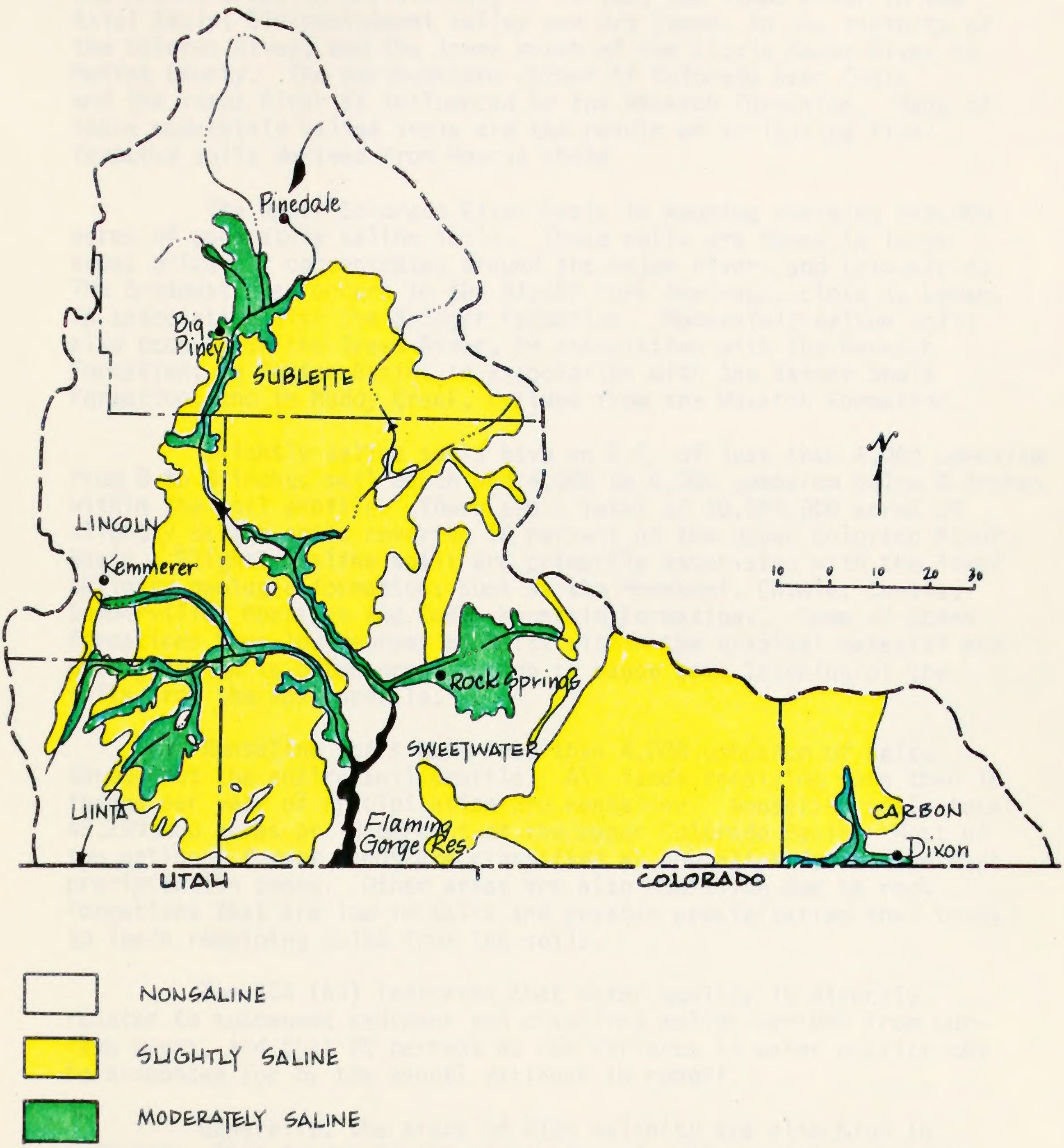



Figure 3. GENERAL SOIL SALINITY CLASSES FOR WYOMING

and McElmo Creek in the vicinity of Cortez; the Yampa River in the Axial Basin; Disappointment Valley and Dry Creek, in the vicinity of the Dolores River; and the lower reach of the Little Snake River in Moffat County. The northwestern corner of Colorado near Craig and the Yampa River is influenced by the Wasatch Formation. Many of these moderately saline areas are the result of irrigating fine-textured soils derived from Mancos shale.

The Upper Colorado River Basin in Wyoming contains 649,000 acres of moderately saline soils. These soils are found in large areas primarily concentrated around the major rivers and tributaries. The broadest area occurs in the Blacks Fork drainage, close to Lyman, in association with the Bridger Formation. Moderately saline soils also occur near the Green River, in association with the Wasatch Formation; in Baxter Basin, in association with the Baxter Shale Formation; and in Muddy Creek, derived from the Wasatch Formation.

Slightly saline soils have an E.C. of less than 4,000 μmhos/cm from 0 to 8 inches soil depth and 4,000 to 6,000 μmhos/cm below 8 inches within the soil profile. There are a total of 10,568,000 acres of slightly saline soils covering 18 percent of the Upper Colorado River Basin. Slightly saline soils are primarily associated with the lower salinity geologic formations such as the Moenkopi, Chinle, Curtis, Summerville, Morrison and Cedar Mountain Formations. Some of these formations have low degrees of salts within the original material and precipitation is often great enough to cause some leaching of the salts from the soil profile.

Nonsaline soils have less than 4,000 μmhos/cm of salts throughout the entire soil profile. All lands receiving more than 16 inches per year of precipitation are nonsaline. Nonsaline soils total 46,299,000 acres or 78 percent of the Upper Colorado Basin. Most of the national forest lands are classified as nonsaline due to the high precipitation zones. Other areas are also nonsaline due to rock formations that are low in salts and greater precipitation that tends to leach remaining salts from the soils.

The SCS (63) indicates that water quality is directly related to suspended sediment and dissolved solids derived from surface areas, and that 90 percent of the variance in water quality can be accounted for by the annual variance in runoff.

Generally, the areas of high salinity are also high in sediment. This is due to the dispersion of soil particles near the surface in high sodic soils which causes a surface fluff that is easily eroded during summer rainstorms. A ratio of salt to sediment has been estimated at 0.51 to 1.00 on the Blacks Fork River and 1.00 to 3.44 on the Green River. It is assumed that by reducing sediment yield the salt load will also be reduced (63).

## C. Vegetation

The Upper Colorado River Basin falls within the Great Basin and Cordilleran Forest Provinces according to Gleason and Cronquist (23). The most important climatic factors which effect vegetation are temperature and precipitation. Also the amount and kinds of salts in the soil have a definite influence upon the kind of species growing on a site.

At the upper reaches of elevation, length of growing season or the number of consecutive days having temperatures above a critical point determine vegetation boundaries. At lower elevations plant boundaries are more effected by the ability of a plant to withstand desiccation. Degree of slope, amount of sunlight reaching a site (exposure), and soil characteristics (depth, particle size, water holding capacity) are factors which can extend plant boundaries above or below its normal range of altitude (23).

Salt in very high concentrations such as found in playas, around saline seeps, and compacted clay soils in small depressions (pan spots) can reduce plant density. Where salt content of the soil is low to moderate, percent ground covered by vegetation is determined by effective soil moisture and grazing pressure.

Goodin (24) states that "moisture is probably the most important formative factor in determination of vegetative type (community), particularly in arid and semiarid regions, but the chemical constituents of the soil determine to a very great extent the vegetational parameters." He also describes "vegetation patterns" over a given saline area as a "complex mosaic" resulting from interactions between salts and precipitation.

Caution must be exercised when using plants as a precise indicator of the level of salinity. Branson, et al, (8) state that "In general, the greater the salt tolerance of a specie, the wider the range of salinity of the soils on which it grows." Greasewood, nuttall saltbush, four-wing saltbush, and shadscale are all very widely distributed salt tolerant and drought resistant plants. They also point out that ". . . . soil-moisture relationships (stress) are the primary cause of different plant communities."

Malekuti (45) found that salt tolerant plants increase the sodium concentration of surface soils. Salts from lower soil horizons are taken up by roots and deposited on leaf surfaces during transpiration. Rain then washes salts from leaves onto the soil. He also states that this process is a minor contributor to the total salt problem.

The composition of plants within a community is also affected by grazing. Marquiss and Lang (47) made a study of two relict (ungrazed) areas on shallow soil sites in Sweetwater County, Wyoming,

and similar adjacent grazed areas. They found that grazing had caused a shift in species composition and percent ground cover. Grazed areas had a greater number of forb species, shrub ground cover had increased, and grass cover was reduced. Results of several years study on the same sites showed climatic fluctuations were reflected in proportional changes in species composition and ground cover. However, variations were greatest on grazed areas. Relict areas were less affected by changes in amount of rainfall. Soil analysis showed that only slight differences in soil properties existed between sites.

The control of wildfire during the last 50 to 60 years has brought about changes in plant communities. Fire favors grass species while the absence of periodic fires allows the establishment of shrub and tree species. Questions exist today concerning the form of plant most effective in controlling erosion, i.e., reducing impact of raindrops, slowing movement of overland flow of water, or reducing concentration time of flood water. Early literature based on observation, but little research, suggests that grass plants offer better protection for the soil against erosion than shrubs. However, recent research indicates that no significant differences between pinyon, juniper, sagebrush, and grass can be documented (1, 6, 25, 29, 60, 73).

Figure 4 is used to demonstrate vegetation communities as they exist in general or could potentially exist in the natural environment under present climate and soils. In the following narrative, communities important to the salinity problem are evaluated as to the relative volume of water they produce with their associated salt content; level of geologic erosion; and susceptibility to increased sediment loss as a result of overgrazing, fire, logging, recreation, etc. Table 6 lists the most important plant species found in each of the natural vegetation communities (3, 4, 22, 34, 50).

1. Alpine and Barren

The alpine and alpine barren community occurs above timberline at elevations of between 11,000 to 12,000 feet in Colorado and Utah and from 9,000 feet upward in Wyoming (50). This community is fragile and the natural balance easily upset by grazing or concentrated recreational use. Good quantities of very high quality water are produced.

2. Western Spruce-Fir-Douglas Fir Forest

The high altitude coniferous forests have been combined in order to reduce the number of separate communities shown in Figure 4. For purposes of the salinity study these communities are quite similar. The spruce-fir-douglas fir forests are found within a range of

LEGEND

| | |
|---|---|
| A | Alpine Meadows - Barren (Agrostis, Carex, Festuca, Poa) |
| B | Western Spruce-Fir-Douglas Fir (Picea-Abies-Pseudotsuga) Forest |
| C | Douglas Fir (Pseudotsuga) Forest |
| D | Pine-Douglas Fir (Pinus-Pseudotsuga) Forest |
| E | Ponderosa Pine (Pinus) Forest |
| F | Juniper-Pinyon (Juniperus-Pinus) Woodland |
| G | Mountain Mahogany-Oak Scrub (Cercocarpos-Quercus) |
| H | Sagebrush-Grass (Artemisia-Agropyron) |
| I | Foothills Prairie (Agropyron, Festuca, Stipa) |
| J | Galleta-Three awn (Hilaria-Aristida) Shrubsteppe |
| K | Grama-Galleta (Bouteloua-Hilaria) Steppe |
| L | Blackbrush (Coleogyne) |
| M | Saltbush (Atriplex) |
| N | Greasewood (Sarcobatus) |

Figure 4. Natural Vegetation Communities in the Upper Colorado River Basin

Adapted from the National Atlas

Figure 4. VEGETATION OF COLORADO

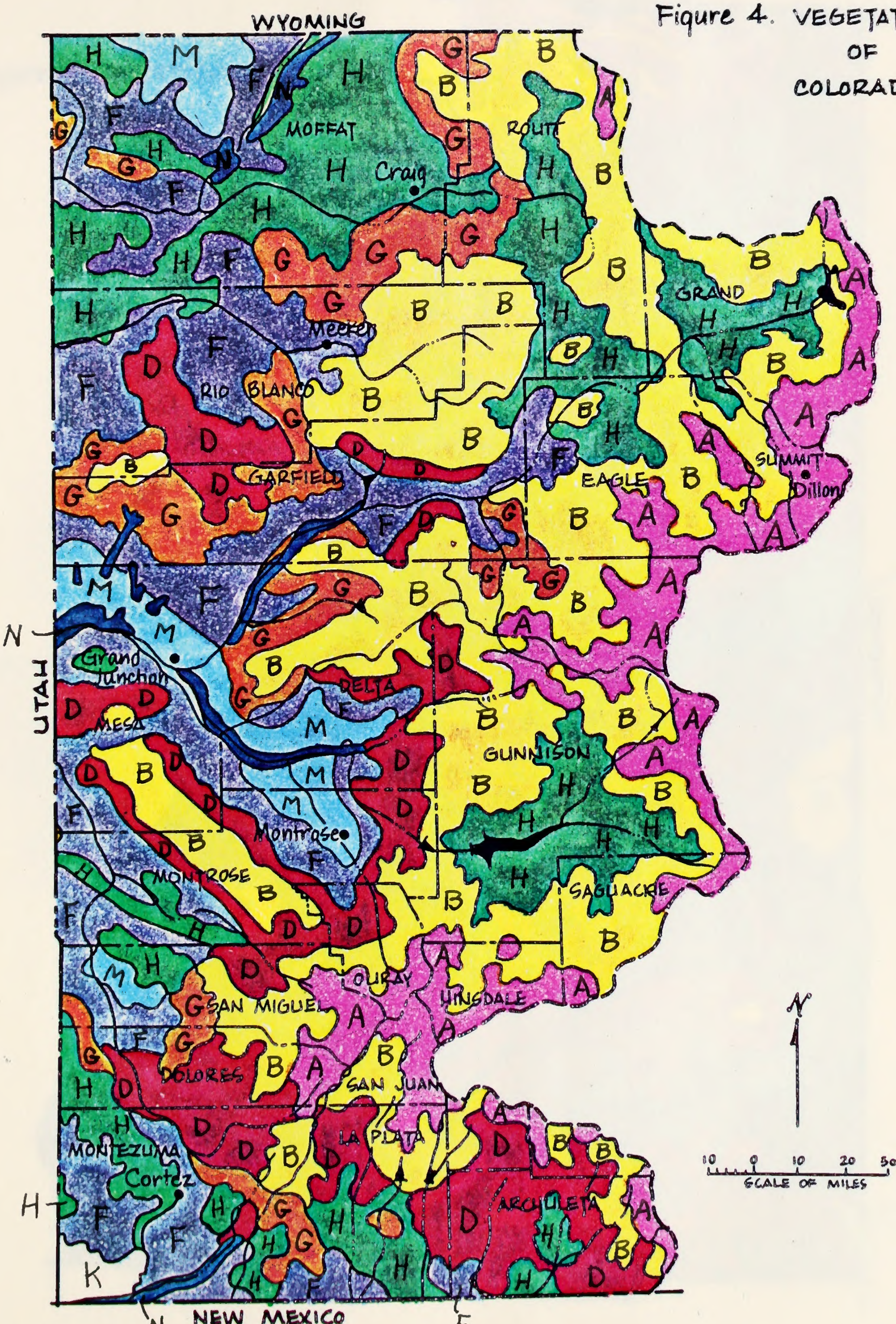
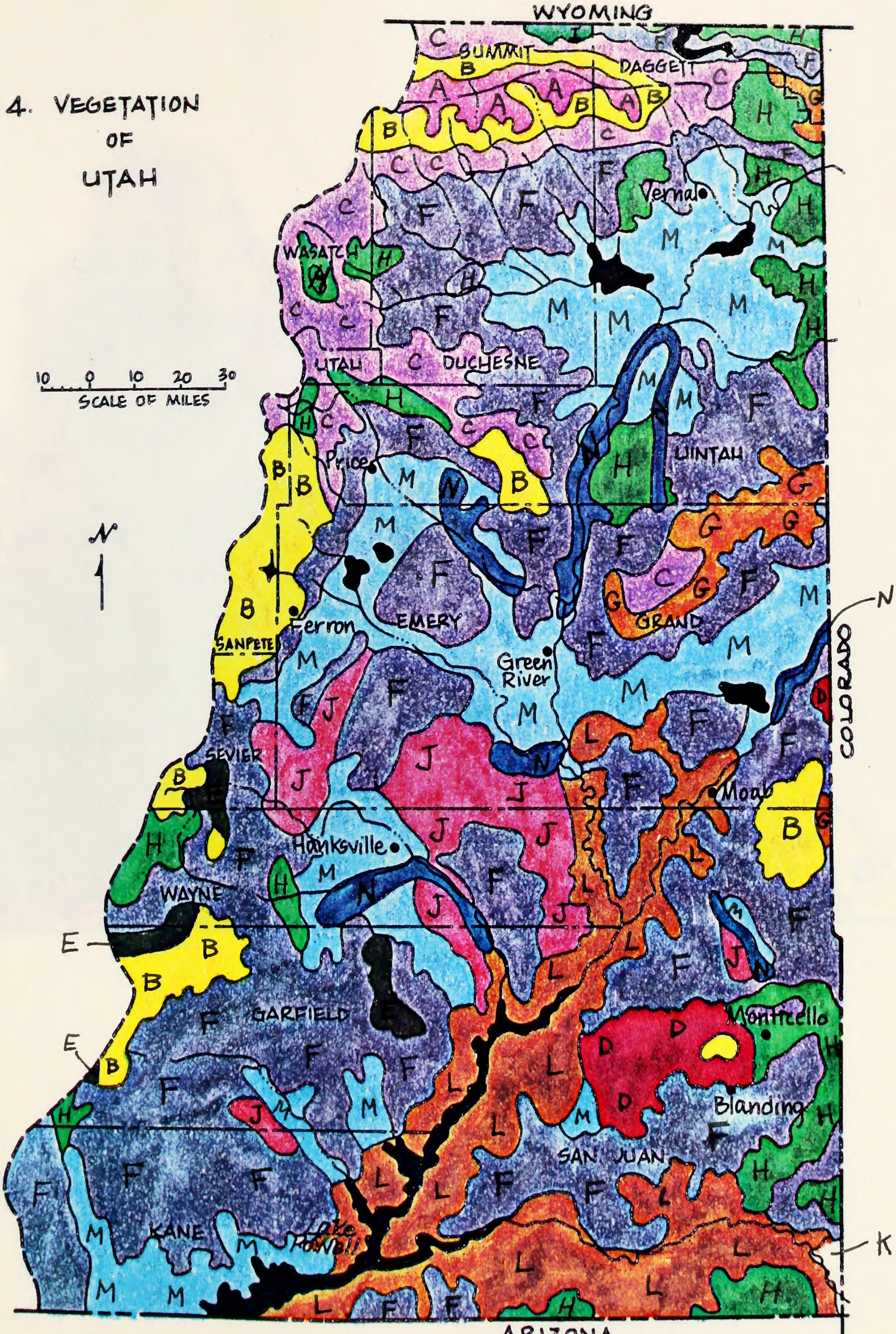


Figure 4. VEGETATION OF UTAH



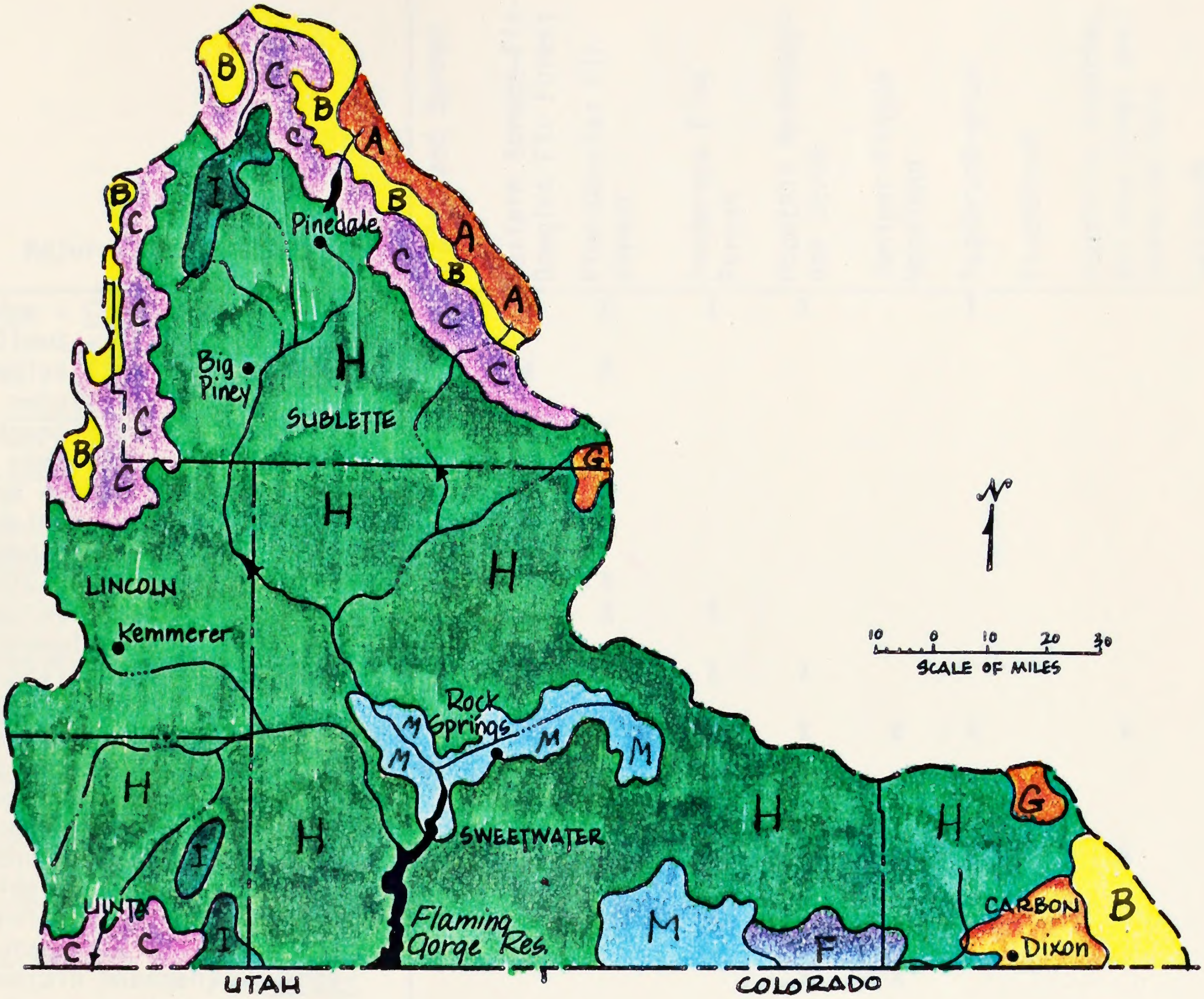



Figure 4. VEGETATION OF WYOMING

Table 6. Plant Species by Natural Vegetation Community

| Major Plant Species | Alpine and Barren | Western Spruce-Fir-Douglas Fir Forest | Pine-Douglas Fir Forest | Ponderosa Pine Forest | Mountain Mahogany-Oak Scrub | Juniper-Pinyon Woodland | Sagebrush-grass | Blackbrush | Foothills Prairie, Galleta-Three awn, Grama-Galleta | Saltbush | Greasewood |
|---|---|---|---|---|---|---|---|---|---|---|---|
| sedge - Carex spp. | X | X | X | X | X | | X | | | | |
| willows - Salix spp. | X | | | | | | | | | | |
| douglas fir - Pseudotsuga menziesii | | X | X | | | | | | | | |
| lodgepole pine - Pinus contorta | | X | X | | | | | | | | |
| blue spruce - Picea pungens | | X | X | | | | | | | | |
| engelmann spruce - Picea engelmannii | | X | X | | | | | | | | |
| white fir - Abies concolor | | X | X | | | | | | | | |
| quaking aspen - Populus tremuloides | | X | X | X | | | | | | | |
| mountain brome - Bromus carinatus | | X | X | X | X | | | | | | |
| prairie junegrass - Koeleria cristata | | X | X | X | X | X | X | | X | | |
| ponderosa pine - Pinus ponderosa | | | X | X | | | | | | | |
| Idaho fescue - Festuca idahoensis | | | X | X | X | X | X | | X | | |
| serviceberry - Amelanchier utahensis | | | | X | X | X | | | | | |
| mountain mahogany - Cercocarpus montanus | | | | | X | X | | | | | |
| big sagebrush - Artemisia tridentata | | | | X | X | X | X | | | | |
| hairy goldaster - Chrysopsis villosa | | | | X | X | X | X | | | | |
| Colorado rubberweed - Hymenoxys richardsoni | | | | X | X | X | X | | | | |
| bluebunch wheatgrass - Agropyron spicatum | | | | X | X | X | X | | X | | |
| needle-and-threat - Stipa comata | | | | X | X | X | X | | X | | |
| blue grama - Bouteloua gracilis | | | | X | X | X | X | X | X | | X |
| scarlet globemallow - Sphaeralcea coccinea | | | | X | X | X | X | X | X | | |

Table 6 - Continued

| Major Plant Species | Alpine and Barren | Western Spruce-Fir-Douglas Fir Forest | Pine-Douglas Fir Forest | Ponderosa Pine Forest | Mountain Mahogany-Oak Scrub | Juniper-Pinyon Woodland | Sagebrush-grass | Blackbrush | Foothills Prairie, Galleta-Three awn, Grama-Galleta | Saltbush | Greasewood |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Utah juniper - *Juniperus osteosperma* | | | | | | X | | | | | |
| pinyon pine - *Pinus edulis* | | | | | | X | | | | | |
| snakeweed - *Gutierrezia sarothrae* | | | | | X | X | X | X | X | | |
| gumweed - *Grindelia squarrosa* | | | | X | X | X | X | X | X | | X |
| fourwing saltbush - *Atriplex canescens* | | | | | | X | | | X | X | X |
| galleta grass - *Hilaria jamesii* | | | | | | X | X | X | X | X | X |
| indian ricegrass - *Oryzopsis hymenoides* | | | | | | X | X | | X | X | |
| sand dropseed - *Sporobolus cryptandrus* | | | | | | X | | X | X | | |
| Kentucky bluegrass - *Poa pratensis* | | | | X | X | X | | | X | | |
| mutton grass - *P. fendleriana* | | | | | X | X | X | | X | | |
| western wheatgrass - *Agropyron smithii* | | | | X | X | X | X | | | | |
| blackbrush - *Coleogyne ramosissima* | | | | | | | | X | | | |
| shadscale - *Atriplex confertifolia* | | | | | | | | | | X | X |
| nuttall saltbush - *A. nuttallii* | | | | | | | | | | X | |
| mat saltbush - *A. corrugata* | | | | | | | | | | X | |
| budsage - *Artemisia spinescens* | | | | | | | | | | X | X |
| greasewood - *Sarcobatus vermiculatus* | | | | | | | | | | | X |
| tamarix - *Tamarix gallica* | | | | | | | | | | | X |
| narrowleaf cottonwood - *Populus angustifolia* | | | | | | | | | | | X |
| saltgrass - *Distichlis stricta* | | | | | | | | | | | X |

elevations from 7,000 to 11,500 feet (20, 34, 53). The pure douglas fir forest occurs at elevations from 6,000 to 8,500 feet. Water quality from high mountain country is generally good; total dissolved solids is low, not exceeding an electrical conductivity (E.C.) of 50 to 100 µmhos/cm. Volume of water is high and discharge is fairly constant throughout the base flow period.

### 3. Pine-Douglas Fir Forest

The pine-douglas fir forest occurs over a wide range of sites at elevations from 6,000 to 9,000 feet in the Colorado River Basin. It is a transition zone between the higher elevation western spruce-fir-douglas fir and more pure douglas fir forest, and the lower elevation ponderosa pine forest. For a description of plants found in this community, see Table 6. Water yield and quality would reflect aspects of both the spruce-fir and ponderosa pine forests depending upon elevation and geology.

### 4. Ponderosa Pine Forest

The ponderosa pine forest ranges in elevation from 5,500 to 9,000 feet in the Upper Colorado River Basin. Volume of water from the pine forest is lower than from the high elevation spruce-fir forests and may cease as surface flow during the hot summer, because of lower precipitation, higher temperatures and increased evapotranspiration. Water quality is fair, E.C. can vary from 200 to 700 µmhos. The ponderosa pine forest is more accessible to man and has historically sustained greater use. This does not mean that pine watersheds would not benefit from better resource management. Grazing is an extensive use because ponderosa pine stands tend to be open thus providing room for understory forage plants to grow.

### 5. Mountain Mahogany-Oak Scrub

Mountain brushlands are located as a transition zone between woodlands and conifer forests, see Figure 4, at an elevation of from 6,000 to 8,000 feet. Volume and quality of water yielded from brushlands is comparable to water yield from the ponderosa pine forest. Use by livestock and the need for proper grazing management is also similar. Brushlands provide extremely important wildlife habitat. Livestock must be managed so that competition for forage between wildlife and domestic animals is kept at a reasonable level. Overgrazing would result in watershed damage and adversely affect water quality.

### 6. Juniper-Pinyon Woodland

The juniper-pinyon woodland community is located in the foothills and plateaus below the ponderosa pine region at elevations ranging between 5,000 to 7,500 feet. Base flow water produced

by the juniper-pinyon woodland region is minimal and comes from springs and seeps. Water yielded is primarily from spring snowmelt and runoff from localized summer thundershowers.

The juniper-pinyon, sagebrush-grass, blackbrush, and grassland communities do not contribute to deep seepage and extensive ground water from the general soil surface because of the high evapotranspiration rate and relatively low precipitation (27). Much of the water received as rain or snow is intercepted by crown canopies of juniper and pinyon trees and shrubs. It is then evaporated into the atmosphere, or excess water falls to the ground and is absorbed by the layer of litter (needles and leaves), or may, in the case of juniper, run down the tree trunk and be absorbed by the thick stringy bark before it can reach the ground. A storm in excess of 0.25 inches (within a relatively short period of time) is required to produce any overland flow.

Water from higher elevation forests moves through the juniper-pinyon woodland on its way to large main streams. Because of high temperatures and lower precipitation in the woodland region, some of the water transported through is consumed. The remaining water contains salts at a higher concentration but not always at an increased load. Sediment production from woodlands is moderate to high during severe summer thundershowers.

Grazing is the predominant use on juniper-pinyon woodlands. Grazing management can result in improved plant health and vigor, and increased ground cover. The effects of trampling by livestock on loss of sediment for each soil type needs to be determined, both under present grazing practices and under intensive grazing management.

Off road vehicle (ORV) use by hunters and other recreationists using jeeps and motorcycles is a growing use on NRL, especially in the juniper-pinyon woodland. Erosion from vehicle tracks which tear up vegetation and loosen soil can be very damaging with effects lasting years after vehicle use has ceased.

7. Sagebrush-Grass

The big sagebrush-grass community is found at the same elevations as the juniper-pinyon community, between 5,000 and 7,500 feet. The hydrology of the sagebrush-grass community is similar to the juniper-pinyon woodland. The resource use patterns are also quite similar.

8. Blackbrush

The blackbrush community is confined to the State of Utah, mostly along the San Juan River and Lake Powell, see Figure 4, at elevations ranging between 4,000 and 5,000 feet. The natural dense crown cover of blackbrush, erosion pavement and cryptogams offer protection against erosion. Water is yielded from the blackbrush region on an intermittent basis following thunderstorms. Sediment yield is low to moderate under stable soil conditions. Amount of salt would be low to moderate depending upon surface geology, but no high salt levels are known to exist. Heavy grazing or fire can expose the soil to accelerated erosion.

9. Foothills Prairie, Galleta-three-awn, Grama-Galleta

The foothills prairie grassland community is a small area in southwestern Wyoming, see Figure 4, within an elevation range of 6,000 to 7,000 feet. The galleta-three-awn and grama-galleta grassland communities, see Figure 4, are found at elevations between 4,000 to 6,000 feet in Colorado and Utah. The grassland areas are hydrologically similar to the juniper-pinyon and sagebrush-grass regions.

10. Saltbush

The saltbush community is found within an elevation range of 4,000 to 6,000 feet. Saltbush grows characteristically on low to moderately saline soils derived from salt bearing geological formations such as marine shales. Water yielded from the saltbush community comes as high peak runoff following high intensity thundershowers (greater than 0.25 inches) of short duration. Water from gentle long duration storms (characteristic of winter frontal systems) generally remains on site and is later lost to the atmosphere through evapotranspiration. Runoff generally does not exceed 0.5 inches per unit area per year.

Sediment yield is low to moderate under normal conditions where vegetative ground cover is 15 to 25 percent. This offers protection from erosive forces of raindrops and overland flow of water. Sediment yield is high on soils derived from Mancos or other marine shales, and where vegetative cover is very sparse or soil has been compacted because of trampling by livestock. The E.C. of water coming from the saltbush community ranges from 300 µmhos/cm to 2,400 µmhos/cm depending upon the salinity of the soil and the amount and sources of sediment carried in the water.

11. Greasewood

The greasewood community is found along water courses throughout the Upper Colorado River Basin within a wide range of

elevations from 3,600 to 6,500 feet. Water yielded from the greasewood community specifically is very low because of the restricted acreage of greasewood sites. It occupies a narrow, relatively flat band of land along drainage channels, see Figure 4. However, a large volume of water passes through the greasewood community, as it collects from larger surrounding plant communities. Most of the rivers in the Upper Colorado River Basin pass through the greasewood community at some point along their courses.

Sediment load from the greasewood community can be very high depending upon the amount and velocity of water flowing through the community, amount of protective vegetative cover, steepness of channel sides, and channel depth and slope, (60). Johnson and Hanson (40) found little sediment being yielded by upland sites during years of low precipitation, while at the same time large quantities of sediment were yielded by "steep, eroding streambanks and near-channel slopes" of downstream areas. Much sediment comes from the channel itself. Salt levels of water flowing through the greasewood community are generally high. Figure 5 shows straight walls of a channel in valley alluvium with large chunks of soil material sluffing off into the channel floor. Note the white evaporites along the waters edge.

Greasewood communities have historically received heavy grazing pressure by livestock because of the available water, flat topography, and rock free soils. Reduced grazing pressure would result in increased protective vegetation which would further result in lower sediment loss and lower salinity. However, many factors are acting upon the hydrology of narrow river channels which make the picture much more complex than this simple analysis would suggest. Schumm and Hadley (58) found evidence which indicates channel degradation and agradation is a continuing cyclic process which may be tied to climatic changes more than to heavy grazing. Hastings and Turner (35) point to a number of authors who subscribe to this thesis.

Figure 5. Channel Bank Erosion in Mancos Derived Alluvium.
Note also evaporite along the stream channel.

## D. Hydrology

### 1. Water Quality

The salinity of the Colorado River is dependent upon many factors such as: (a) water yield; (b) geologic origin of soils; (c) subsurface geology; (d) amount of irrigation; (e) municipal and industrial uses; (f) transmountain diversions; and (g) other minor uses. Salinity of water is reported in total dissolved solids concentration. The dissolved solids are generally reported in mg/l or parts per million (ppm). They are considered equivalent and used interchangeable for concentrations below 7,000 mg/l. An indicator of water salinity is the specific conductance of the water as measured by an E.C. meter in micromhos per centimeter (μmhos/cm). The relationship between specific conductance and total dissolved solids is a function of the chemical makeup of the water and is frequently represented with a linear relationship as shown:

$$S = KA$$

where $S$ = salinity in milligrams per liter

$K$ = conductance in μmhos/cm at $25^{\circ}$ Centigrade

and,

$A$ = conversion factor

The conversion factor "A" is usually between the values of 0.55 and 0.75 (36), but may range from 0.5 to 0.95. The factor "A" has been assumed to be equal to 0.65 for use in this report since sufficient data is not available to establish the actual relationship for all streams.

Long-term water quality data from the Colorado River Basin is limited and has been collected by the Geological Survey (GS). They report stream salinity in salt concentrations (mg/l) and total volume (tons per day). These stations are located on the major tributaries and are designed to show total salt loading. The collection system was not designed to isolate individual areas that have high salt yields or to quantify salts from a specific source. Other agencies have collected data for short periods of time. Table 7 contains a summary of most stations where water quality data is collected in the Upper Basin and contains salt concentrations for high and base flow (17) periods. The BLM has collected some data relating to contributions from NRL. Data collected by BLM is contained in an open-file report in the files of BLM, Denver Service Center, Division of Standards and Technology, Watershed Staff.

Table 7. Mean TDS Concentrations for Key Stations in the Colorado River Basin, Water Years 1959-1963, and Average Annual Discharge for Period of Record

| River | Location of Station | Base b/ Months (mg/l) | All Months (mg/l) | Runoff c/ Months (mg/l) | Annual Runoff (Acre ft) |
|---|---|---|---|---|---|
| Colorado | Hot Sulphur Springs, Colo. | 94 | | 77 | - |
| | Glenwood Springs, Colo. | 402 | | 208 | - |
| | Cameo, Colorado | 732 | | 265 | 2,785,000 |
| | Cisco, Utah | 1,152 | | 316 | 5,552,000 |
| | Lees Ferry, Arizona | 1,015 | | 477 (372)a/ | 12,923,000 |
| | Grand Canyon, Arizona | 1,069 | | 512(401) | 12,260,000 |
| | Hoover Dam, Arizona-Nevada | | 677 | | 9,730,000 |
| | Imperial Dam, Arizona-Calif. | | 792 | | - |
| | Yuma, Arizona | | Changing | | - |
| San Juan | Archuleta, New Mexico | 259 | | 124 | 943,300 |
| | Bluff, Utah | 869 | | 316 | 1,873,000 |
| Green | Green River, Wyoming | 441 | | 265 | 1,237,000 |
| | Greendale, Utah | 557(533) | | 407 (337)a/ | 1,471,000 |
| | Ouray, Utah | 592 | | 240 | - |
| | Green River, Utah | 722 | | 276 | 4,607,000 |
| Eagle | Gypsum, Colorado | 679 | | 156 | 409,300 |
| Gunnison | Grand Junction, Colorado | 1,220 | | 408 | 1,855,000 |
| Dolores | Cisco, Utah | 2,140 | | 464 | 507,200 |
| Animas | Farmington, New Mexico | 552 | | 203 | 658,600 |
| Henrys Fork | Linwood, Utah | 1,200 | | 615 | 60,130 |
| Yampa | Maybell, Colorado | 317 | | 112 | 1,121,000 |
| Little Snake | Lily, Colorado | 532 | | 147 | 412,200 |
| Duchesne | Randlett, Utah | 1,220 | | 999 | 428,900 |
| White | Watson, Utah | 601 | | 303 | 508,600 |
| Price | Woodside, Utah | 3,950 | | 4,740 | 73,900 |
| San Rafael | Green River, Utah | 722 | | 276 | 113,000 |

a/ Figures in parentheses are for water years 1959-62. Closure of Glen Canyon and Flaming Gorge dams caused abnormally high TDS concentrations at downstream stations in 1963.

b/ August through March.

c/ April through July.

Adapted from "The Mineral Quality Problem in the Colorado River Basin," Appendix A, Environmental Protection Agency, 1971.

Water from high mountain watersheds contains low concentrations of salts, mainly calcium bicarbonate. As water moves through river systems, the major constituents change from calcium bicarbonate to calcium sulfate, sodium sulfate and sodium chloride. This shift can be caused by several factors, such as: (a) change in the salinity of alluvial material the water contacts; (b) the chemical makeup of soils and geologic formations contributing surface runoff and groundwater; and (c) relative activity of the salt producing ions. Sodium and chloride are the most active ions and tend to replace or exchange with other elements in solution as well as have a high solubility level.

The mainstem of the Colorado River between its confluence with the Eagle River and Roaring Fork takes into solution significant amounts of sodium chloride to form a chemical composition of calcium, sodium bicarbonate, chloride. This composition remains relatively constant until its confluence with the Gunnison River.

The Gunnison River receives large quantities of salt from the North Fork and Uncompahgre Rivers. Additional salt loads are picked up from irrigation return flow and natural runoff before it discharges into the Colorado River. The impact of the Gunnison River and irrigation in Grand Valley on salinity of the Colorado River is great. Sulfates become the major anion along with lesser concentrations of the calcium and sodium cations. The water character remains essentially the same until it reaches the Dolores River.

The Dolores River at its headwaters contains a low concentration of calcium bicarbonate but takes into solution a much greater concentration of sodium chloride as it passes through the Paradox Formation. The San Miguel River which enters the Dolores below the Paradox Dome contains a moderate amount of calcium sulfate. The chemical composition of the Dolores River below the confluence with the San Miguel is a sodium, calcium, chloride sulfate. The Dolores River causes an increase in salinity of the Colorado River and increases the sodium and chloride contents, with sodium at approximately the same level as calcium, and chlorine at about the same level as bicarbonate. Sulfate is the most prevalent anion. As the Colorado River approaches the confluence with the Green River, the concentration of salts increases, although the relative chemical composition of the elements does not change.

The water of the San Juan River at its upper reaches contains primarily calcium bicarbonate. At its confluence with the Colorado River, salt concentrations change to calcium-sodium sulfate. The La Plata River is high in calcium-magnesium sulfate while McElmo Creek is magnesium-calcium sulfate.

The headwaters of the Green River Basin of Wyoming contain a relatively low concentration of salts. The major sources of salinity in Wyoming are the Big Sandy, Blacks Fork, and Henrys Fork drainages. Salts in the Big Sandy come from irrigation in the Eden-Farson area and from saline seeps along a 16 mile reach of the river below the irrigation project. This causes characteristics of the water to change from calcium-bicarbonate to sodium-sulfate with a much higher concentration of salinity. Runoff from the western mountains contains about three times more salt than is yielded from the northeastern Wind River Mountains. Salts in the Blacks Fork River come primarily from the irrigated areas near Lyman and Mountain View.

The Yampa and Little Snake River drainages of Colorado and Wyoming yield good quality water containing low concentrations of calcium bicarbonate. The Yampa has a dilution effect on the Green River. The Green River picks up some sulfate between the confluence of the Yampa and the Duchesne River.

The headwaters of the White River yield good quality water which changes gradually over a long reach of stream channel to a higher concentration of calcium-sodium bicarbonate-sulfate. This change is caused by lower elevation streams, such as Piceance Creek that drain salt bearing geologic formations, and interact with lower quality alluvial groundwater and irrigation return flows in the valley bottom.

Waters of the Price River near its mouth have the highest salt concentrations of any of the major tributaries of the Colorado River. Salts are picked up primarily from irrigation return flows of Mancos derived soils, interchange with localized alluvial groundwater and surface runoff from intermittent streams draining Mancos watersheds. The San Rafael River is similar to the Price River. However, it does contain a lower concentration of total dissolved solids.

The Dirty Devil, Escalante and Paria Rivers are located to the west of Lake Powell. These rivers drain watersheds with geology containing lesser amounts of salt; areas of Mancos shale are less extensive. Therefore, the salt load of these rivers is less than other tributaries farther upstream.

2. Salt Load from NRL

The EPA estimates average percentages of total salt load originating in the Upper Colorado River Basin from the following sources as: net runoff from natural lands, 52 percent; irrigated agriculture, 37 percent; natural point sources, 9 percent; and municipal and industrial, 2 percent; see Figure 6. Runoff from natural sources

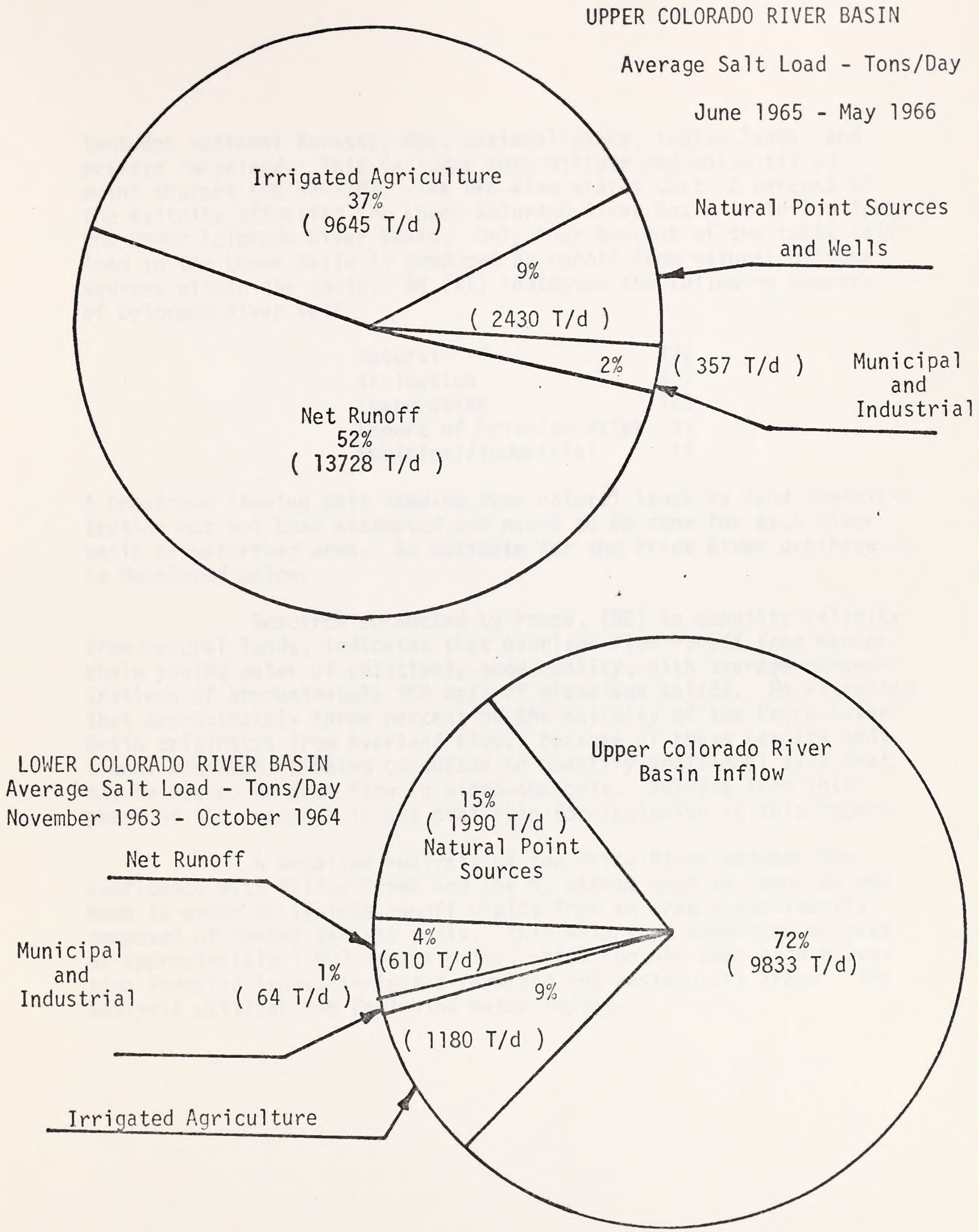



Figure 6. Relative Magnitude of Salt Sources in the Colorado River Basin

Adapted from "The Mineral Quality Problem in the Colorado River Basin," Appendix A, Environmental Protection Agency, 1971.

includes national forests, NRL, national parks, Indian lands, and private rangeland. This includes both diffuse and unidentified point sources (PL 93-320). The EPA also states that 72 percent of the salinity affecting the Lower Colorado River Basin is inflow from the Upper Colorado River Basin. Only four percent of the total salt load in the Lower Basin is produced by runoff from natural diffuse sources within the Basin. BR (11) indicates the following sources of Colorado River salt.

| | |
|---|---|
| Natural | 47% |
| Irrigation | 37% |
| Evaporation | 12% |
| Export of Pristine Water | 3% |
| Municipal/Industrial | 1% |

A breakdown showing salt loading from natural lands by land administration has not been attempted and needs to be done for each river basin or watershed area. An estimate for the Price River drainage is developed below.

Research conducted by Ponce, (52) to quantify salinity from natural lands, indicates that overland flow runoff from Mancos shale yields water of relatively good quality, with average concentrations of approximately 300 mg/l of dissolved solids. He estimated that approximately three percent of the salinity of the Price River Basin originates from overland flow. Because of these results additional research is being conducted to quantify additional salt that may be picked up from flow in micro-channels. Results from this phase of the research is not available for inclusion in this report.

A detailed analysis of the Price River between the confluence with Willow Creek and the GS stream gage at Woodside was made in order to isolate runoff yields from an area predominantly composed of Mancos derived soils. This watershed comprises an area of approximately 1,000 square miles, which contain some high elevation forested lands, irrigated farmland and residential areas. The analysis utilizes the following water budget.

Outflow = Inflow + Imports - CU + X

where:

Outflow = average annual outflow at Woodside

Inflow = inflow at Heiner, Utah

CU = consumptive use of water by 18,000 acres of irrigated crops as given by GS at Woodside gage and is assumed to be two acre feet per acre based on data obtained from BR. The CU is based on Blaney-Criddle equation applied at Castle Dale.

Imports = water imported from Huntington Creek in excess of CU required to irrigate 7,000 acres at an efficiency of 50%.

X = unknown runoff from 1,000 square miles.

Table 8 summarizes results of the water budget analysis using data from two separate periods.

Table 8. Summary of Water Budget Analysis for the Price River Below Willow Creek

| | 1947-57 | 1964-67 |
|---|---|---|
| Inflow (acre feet) | 83,800 | 74,300 |
| Import (acre feet) | 14,000 | 14,000 |
| CU (acre feet) | 36,000 | 36,000 |
| Outflow (acre feet) | 72,800 | 69,600 |
| Estimated Runoff, X (acre feet) | 11,000 | 17,300 |
| Yield in inches/square mile | 0.2 | 0.3 |

The estimated water yield of from 0.2 to 0.3 inches per square mile is an average for the watershed area. It is felt that the estimate is probably high for a typical Mancos shale area because of quantities of good quality water yielded by high elevation forested lands. The estimate also includes natural ground water inflow. Assuming an average salinity concentration of 3,000 mg/l, the area would yield an annual salt load of 45,000 to 67,000 tons annually. This estimate is probably high since most water samples collected with significant amounts of surface runoff had E.C. measurements less than 3,000 µmhos/cm.

The EPA (17) found that about 212,000 tons of salt were produced by irrigation in 1965-66 out of a total basin outflow of 323,000 tons. They attribute natural runoff as contributing 69,000 tons. Data collected for this study would indicate the water quality at Heiner to be about 440 mg/l, while Vaughn Hansen Associates, (65), in 208 studies for the Price area found the concentration ranged from 370 to 760 mg/l. Using the inflow at Heiner of 83,000 acre feet and a concentration of 400 mg/l, the Price River above the major concentration of irrigated lands would yield a total salt inflow of 45,000 tons. Based on the EPA estimate for 1965-66 this would leave about 24,000 tons of salt inflow by surface runoff from natural rangelands for the area downstream of the irrigated lands.

Data collected by the BLM indicates runoff contributed by storms and snowmelt would have a concentration closer to 2,000 mg/l. Using this concentration the salt yield would be approximately 30,000 tons which is in closer agreement with the 1965-66 EPA data. This would give an average annual yield of 30 tons per square mile, which is probably representative of most high salt producing watersheds on NRL.

This analysis shows the need for detailed data collection and analysis to adequately describe and quantify salt yield from specific areas. Analysis of data at Woodside, Utah, in conjunction with the data developed above, would indicate that during periods of below normal runoff salt is being stored in the basin to be flushed out during periods of high runoff. Generally there is a good inverse relationship between discharge and concentration as shown in Figure 7. This relationship is lacking in the Price River at Woodside since some of the higher flows also have higher salt concentrations. For example, Iorns (38) shows an average monthly flow of 300 cfs and a concentration of 3,000 mg/l for July 1957. The variation and lack of correlation is even more dramatic when daily discharge is considered.

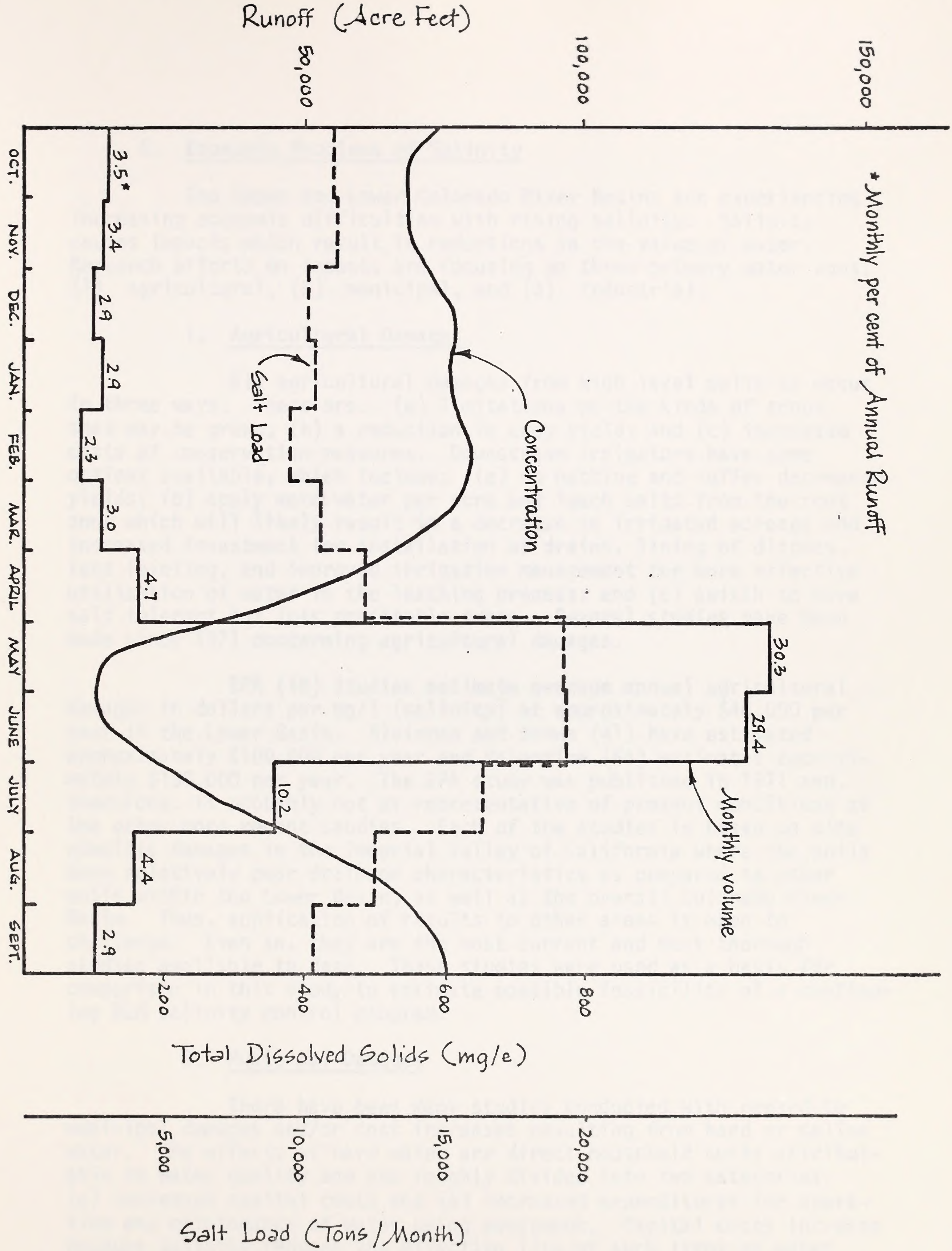



Figure 7. Discharge and Total Dissolved Solids for the Eagle River at USGS Gage at Gypsum, Colorado, for water year 1974.

## E. Economic Problems of Salinity

The Upper and Lower Colorado River Basins are experiencing increasing economic difficulties with rising salinity. Salinity causes impacts which result in reductions in the value of water. Research efforts on impacts are focusing on three primary water uses: (1) agricultural, (2) municipal, and (3) industrial.

### 1. Agricultural Damages

All agricultural damages from high level salinity occur in three ways: These are: (a) limitations on the kinds of crops that may be grown; (b) a reduction in crop yield; and (c) increased costs of conservation measures. Downstream irrigators have some options available, which include: (a) do nothing and suffer decreased yields; (b) apply more water per acre and leach salts from the root zone which will likely result in a decrease in irrigated acreage and increased investment for installation of drains, lining of ditches, land leveling, and improved irrigation management for more effective utilization of water in the leaching process; and (c) switch to more salt tolerant but less profitable crops. Several studies have been made since 1971 concerning agricultural damages.

EPA (18) studies estimate average annual agricultural damages in dollars per mg/l (salinity) at approximately $46,000 per year in the Lower Basin. Kleinman and Brown (41) have estimated approximately $109,000 per year and Valentine (64) estimates approximately $130,000 per year. The EPA study was published in 1971 and, therefore, is probably not as representative of present conditions as the other more recent studies. Each of the studies is based on site specific damages in the Imperial Valley of California where the soils have relatively poor drainage characteristics as compared to other soils within the Lower Basin, as well as the overall Colorado River Basin. Thus, application of results to other areas is open to challenge. Even so, they are the most current and most thorough studies available to date. These studies were used as a basis for comparison in this study to estimate possible feasibility of a continuing BLM salinity control program.

### 2. Municipal Damages

There have been many studies conducted with regard to municipal damages and/or cost increases resulting from hard or saline water. The effects of hard water are direct household costs attributable to water quality and are roughly divided into two categories: (a) increased capital costs and (b) increased expenditures for operation and maintenance of water using equipment. Capital costs increase because salinity reduces the effective life of such items as water pipes, fixtures, and water using appliances. These costs can be partially offset by investment in water softening devices. Operation

and maintenance costs may increase with increased salinity due to expenditures for more frequent repairs of capital cost items, increased use of water softening chemicals, purchase of bottled water, and increased use of soap and detergent.

Valentine (64) estimated annual urban damages to be approximately $125,000 per mg/l when the salinity was projected to be 300 mg/l. Kleinman and Brown (41) estimated that municipal damages are approximately $119,000 per mg/l per year. In a separate study the EPA (18) concluded that municipal damages would increase to more than $3 million annually by 2010.

In another study of residences in Los Angeles County, Eubanks and d'Arge (19) estimated economic losses ranging from $620 to $1,010 per household in present value terms using an 8 percent discount rate. This was based on total dissolved solids increasing from 200 ppm to 700 ppm. A rough extrapolation of these results to the entire Los Angeles area that uses Colorado River water indicates that an attainable reduction of only 10 ppm would result in a saving of about $14 million in present value terms or $112,000 on an annual equivalent basis.

### 3. Industrial Water Damages

The mineral content of water affects corrosion and scale formation in boilers and cooling systems. Minerals in boiler feed water reduce the economic life of the boiler as well as affect the quality of the steam produced. Industrial water users have the option of obtaining higher quality water, at some expense, or more frequently repairing and/or replacing their affected equipment. The EPA (18) has estimated industrial costs to be $1,148 per mg/l per year. The BR (12) estimated damage costs at $1,500 per mg/l per year, which is very comparable to the EPA study, (18).

## IV. FUTURE WATER QUALITY WITHOUT SALINITY CONTROL MEASURES

Future conditions in the Colorado River Basin based on present and future water use are expected to increase the concentration and total salt loading throughout the Basin. As each of the Upper Basin states continue to develop their individual water allocations they will reduce the supply of water available for dilution of water delivered to the Lower Basin states and add to the salt load through return flow (surface and subsurface). Table 9 contains future estimates of salinity, based on the results of studies by the BR, the EPA, Colorado River Board of California, and Water Resources Council.

Table 9. Projected Salinity Concentrations at Imperial Dam (46) (assuming no control program)

| | Milligrams Per Liter by Year | | | | |
|---|---|---|---|---|---|
| Agency | 1980 | 2000 | 2010 | 2020 | 2030 |
| EPA | 1060 | -- | 1220 | -- | -- |
| CRBC | 1070 | 1340 | -- | -- | 1390 |
| WRC | 1260 | 1290 | -- | 1350 | -- |
| BR | 1000 | 1250 | -- | -- | -- |

These projections are expected conditions without a control program to reduce salinity.

The proposed development of additional transmountain or out of basin diversions (above 5,000 feet elevation) to the east slope of the Rocky Mountains in Colorado would remove very high quality water (less than 100 mg/l) from the Colorado River system. This water would normally have diluted lower quality water contributed from saline watersheds at lower elevations. Projected increases in municipal water use would remove relatively good quality water, result in a small loss of water through consumptive use and an increased salt load of water returned to the river system. This addition is a relatively small amount (less than one percent) as predicted by the EPA (18).

The increasing demand for energy production in the Upper Basin will require the consumption of additional water. Use of water for energy can have several effects on concentration of salts in the Colorado River. The processed water, a return flow into the river system, may carry an increased salt load because of the addition of salts leached from materials used in the treatment of water. On the other hand, environmental constraints may require no discharge of processed water. This would have a detrimental effect where the relatively good quality water originally withdrawn had a dilution effect on downstream water. This would be a very important factor since most of the coal, oil, gas, oil shale, and other energy producing minerals are located in watersheds that produce good to high quality water.

Present activities on NRL would not contribute to the increased salt loading as shown in Table 9. However, management practices which are effective in reducing salinity from NRL would have a significant effect in holding salinity levels at Imperial Dam below the predicted levels. The goal of accepted standards set for the Colorado River by the Basin States is to hold salinity at or near the present level.

## V. RESEARCH AND DATA COLLECTED

### A. Current Research Projects

#### 1. Badger Wash Study, Colorado

Salinity data is lacking on NRL. The BLM has contracted with GS to collect water yield, sediment and quality data on three instrumented watersheds. Data on water yield and sediment load has been collected for more than 20 years; therefore, it is the objective of this three year study to correlate sediment and salt concentrations with existing sediment data. This study will attempt to relate salinity to sediment loss through the utilization of sediment data collected over a period of many years.

A significant runoff event occurred this summer (1976) which was not recorded. Batteries were not sufficiently charged to operate sampling equipment. Therefore, no data was collected this year even though the watersheds were instrumented.

#### 2. Colorado State University (CSU) Interflow Study

Two watersheds will be instrumented this fall on marine shales in Colorado and/or Utah to determine the nature and extent of ground water movement laterally through the soil profile above the unweathered parent material (bedrock). Interflow is considered to be movement of water in an unsaturated soil, as well as in a saturated soil. Water moves laterally through the soil profile until the profile is interrupted by a gully channel, where it becomes a part of the channel flow or evaporates on the channel surface. Specific objectives of the study are to determine, (a) the quantity of water moved, (b) forces involved, and (c) how the quality of water is affected as it moves through the soil. Interflow potential will be related to the average annual precipitation, soil characteristics, and salinity of the surface runoff.

#### 3. USU Micro-Channel and Land Treatment Study

The micro-channel portion of the study is designed to isolate mechanisms involved in salt increase of water moving in small channels (cross-sectional area of two square feet) on upland sites. Specific objectives are to determine soil, channel and storm characteristics that affect salt movement.

The land treatment study is designed to determine the effects on salt movement resulting from mechanical modification of soils and vegetative cover. Specific objectives are to determine how hydrologic characteristics of soils have changed as a result of disturbing the soil surface or changing vegetative cover, and how surface hydrology changes occur with time after treatment.

## B. Data Collected

### 1. Soils Data

Soil samples were collected by the BLM on three watersheds and reservoirs in Badger Wash. Each reservoir was transected with a series of auger holes both parallel and perpendicular to the dam face. At each hole samples were taken at one foot intervals to a depth of six feet or to bedrock when above six feet. A total of 39 augerings were performed within the 3 reservoirs, the larger reservoir with 16 and the smallest with 9 holes.

Four pits were dug to bedrock in each watershed surrounding the reservoirs. Soils were chosen to represent predominent soil types and aspects, and samples were collected from each major genetic horizon. These samples were taken to facilitate the comparison between the original soils and resultant sediments trapped in the reservoirs. Samples were also taken of the channel bed upstream of the gaging stations.

Two other soils were also sampled within the Boco Mountain experimental watershed. Both soils had similar morphologies on the same slope and aspect; however, one soil had been converted to grass and the other had remained in native sagebrush.

A total of 221 soil samples were analyzed. Soil texture was measured using the hydrometer method, calcium carbonate was analyzed using the acid neutralization method for alkaline earth, and electrical conductivity and pH were determined from 5:1 water to soil ratio using standard conductivity and pH meters.

### 2. Water Quality Data

Concentration of total salts in water was measured by BLM. Rate of runoff in cfs and suspended sediment concentrations within broad categories of no sediment, low, moderate and high sediment content were estimated. Data was collected at key points along streams. Each location was selected to isolate contributions of salts from a given portion of the watershed, see Figure 8. This collection procedure was designed to separate salt sources by vegetation community, geology, soils, land use, etc. Measurements on streams were taken at points where they left forested lands, woodlands, saltbush sites, Mancos shale areas, before and after leaving irrigated tracts, and the greasewood community.

Very little water quality data has been collected on small streams generally because of their remote location and poor access. This study has concentrated on a few key permanently located measurement stations and utilizing a system of spot measurements at many locations. This is necessary to get a broader picture of water quality throughout the drainage network of small streams coming from NRL.

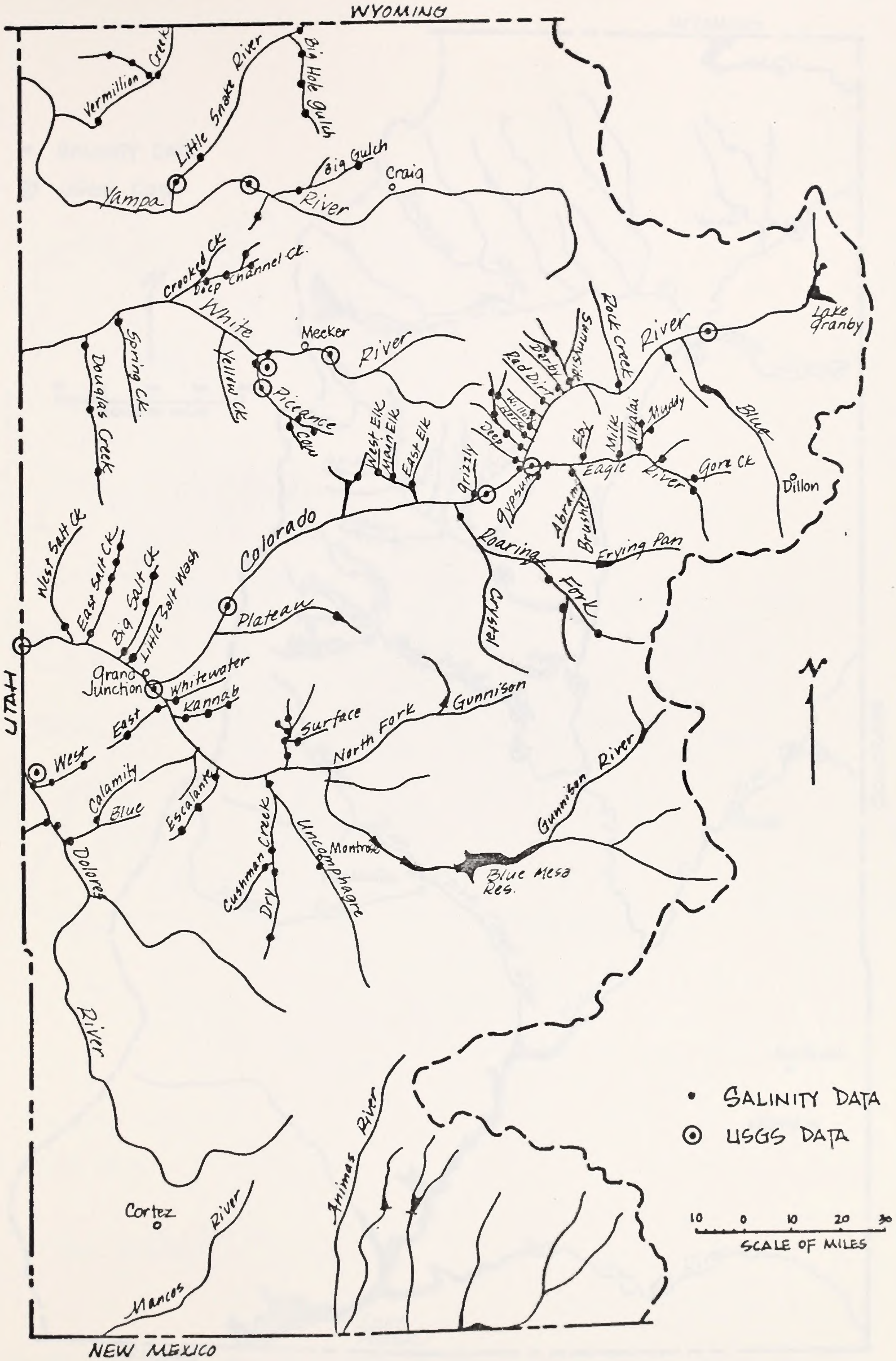



Figure 8. SALINITY STUDY · UPPER COLORADO RIVER BASIN · COLORADO
LOCATION OF WATER QUALITY DATA COLLECTION STATIONS

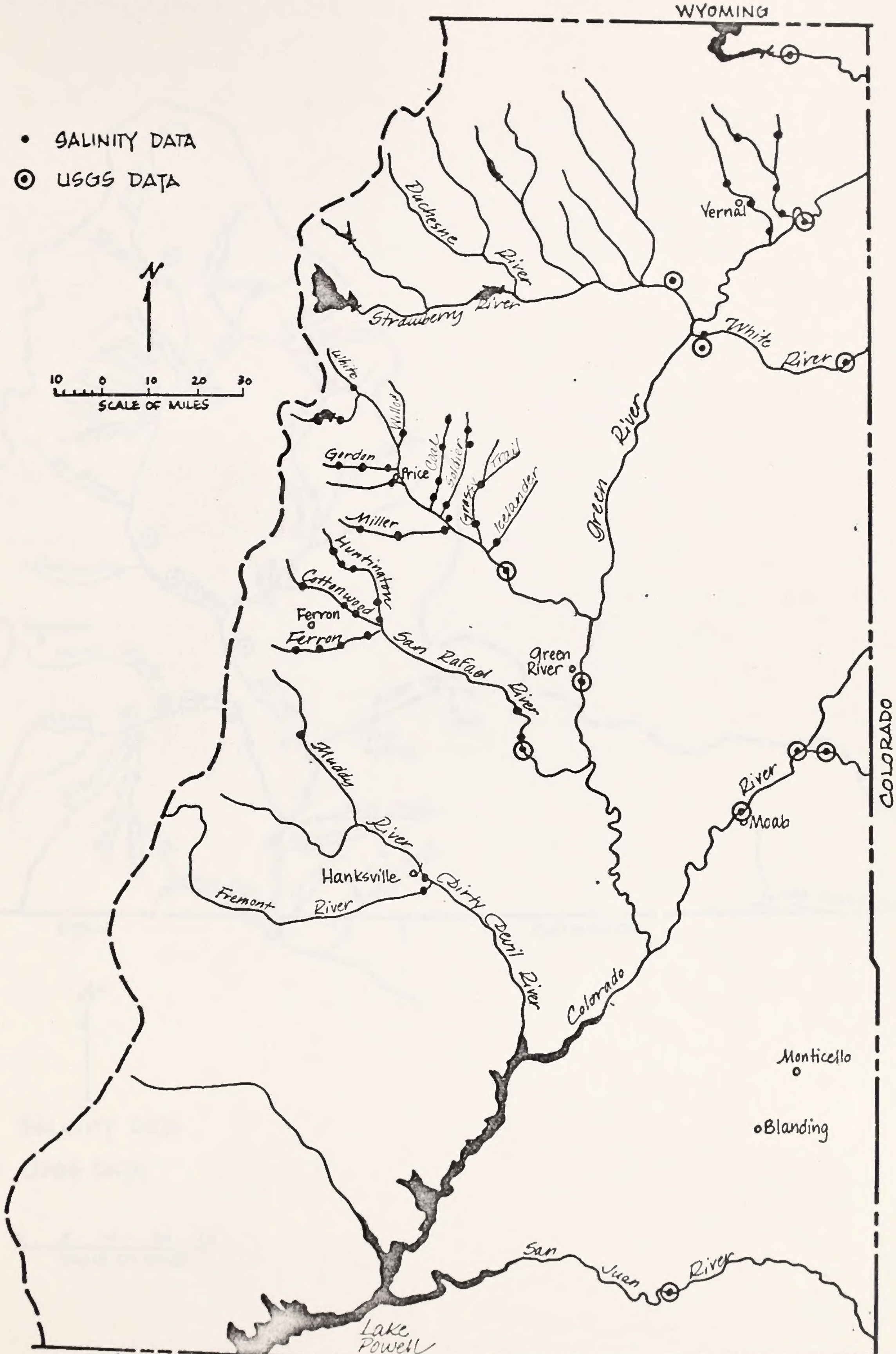



Figure 8. SALINITY STUDY · UPPER COLORADO RIVER BASIN · UTAH
LOCATION OF WATER QUALITY DATA COLLECTION STATIONS

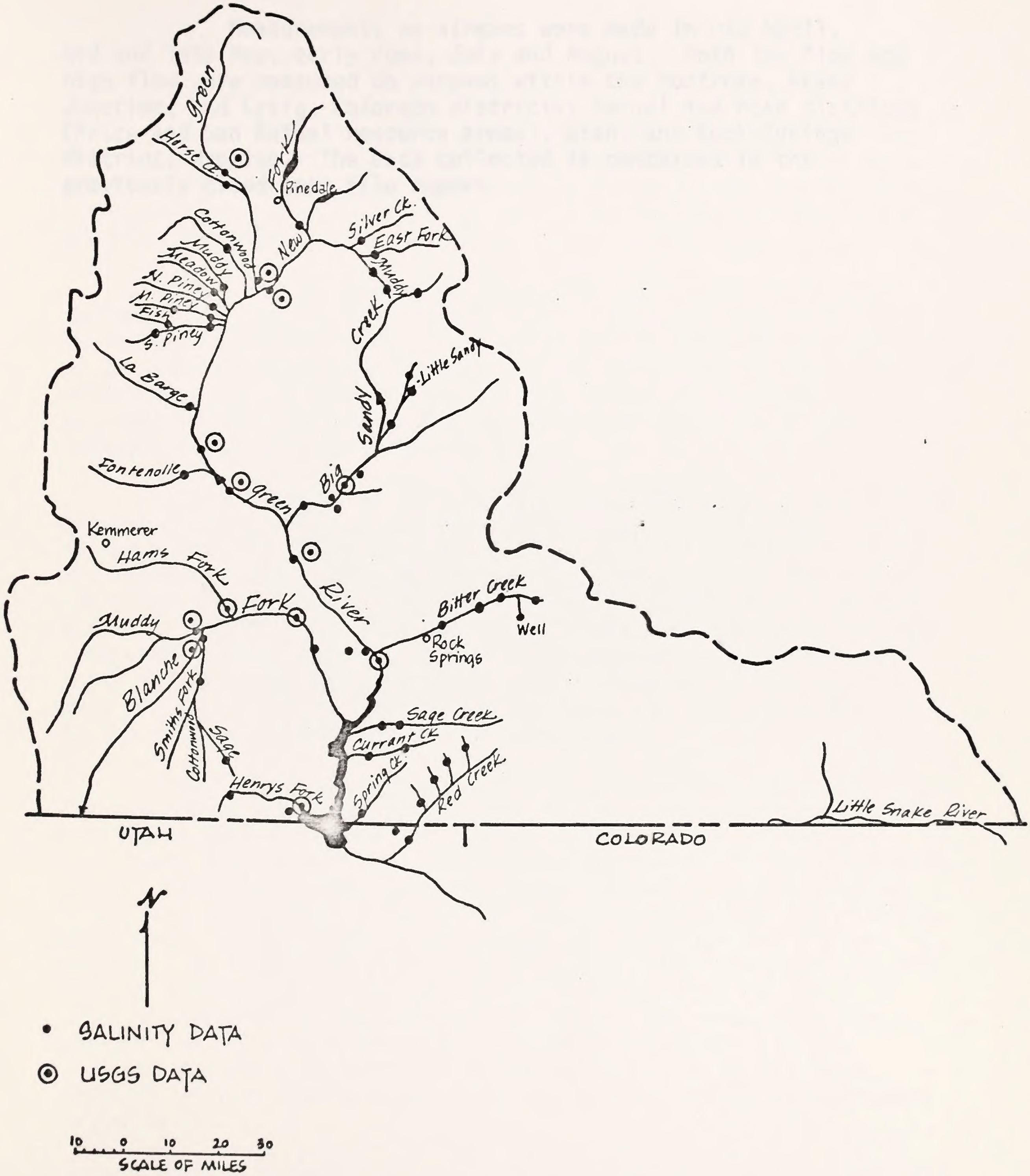



Figure 8. SALINITY STUDY · UPPER COLORADO RIVER BASIN · WYOMING
LOCATION OF WATER QUALITY DATA COLLECTION STATIONS

Measurements on streams were made in mid April, mid and late May, early June, July and August. Both low flow and high flow were measured on streams within the Montrose, Grand Junction, and Craig, Colorado districts; Vernal and Moab districts (Price and San Rafael resource areas), Utah; and Rock Springs district, Wyoming. The data collected is contained in the previously cited open file report.

# VI. RESULTS

## A. Soils

Results of the soil samples taken at Badger Wash indicate that several processes are active within the reservoirs. As sediments are trapped within the reservoirs the salts are free to move upward or downward within the system during periods of evaporation and precipitation.

Data was gathered that showed the relationships between sediment, carbonates, and soluble salts. It is evident that since these reservoirs are trapping virtually all of the salt and sediment, at the time of deposition sediment should have approximately the same conductivity and carbonate level as the upland soils. Because of textural sorting the finer textured materials should be higher in carbonates and salts than the sands.

An evaluation of data revealed that there was no correlation between textural classes and conductivity and that carbonates were not homogeneously mixed throughout the reservoir sediments. There was, however, some subtle relationships between calcium carbonates and clay content. In the West Twin Reservoir, texture of sediment gradually became finer from the gaging station to the center of the reservoir and carbonates also gradually increased. Sediment and salts in the other two reservoirs, Prairie Dog and Middle Basin, were not as closely correlated in the upper six feet, probably due to the coarser texture and greater leaching.

The E.C. of these reservoirs was also distinctly different. The conductivity of the surface foot of the reservoir sediment was much lower than that found at greater depths. This indicates that there were either more salts deposited earlier in the reservoir life or that the surface salts had been leached to greater depths within the sediments. Salts in the larger reservoir at West Twin showed very little differences between the surface and six foot samples. It is believed that most of these salts have been leached through percolation to greater depths than the depth of sampling. This is supported by the observation that as the reservoirs became smaller the salts more abruptly increased with depth. In the smallest reservoir at Prairie Dog the conductivity at six feet was much greater than that found in the surface of the surrounding upland soils.

This data indicates that (1) detention dams are trapping all of the sediment and some, if not all, of the salts; (2) salts move freely through the sediments and are affected by the leaching process.

VI. RESULTS

A. Soils

[illegible] of the soil samples taken at [illegible] that several processes are active within the reservoirs. [illegible]

[illegible] sediments [illegible] should be higher in [illegible] than the sands.

An evaluation of data revealed that there was no correlation between [illegible] water and conductivity [illegible]

[illegible] to the [illegible] and greater leaching.

The E.C. of these reservoirs [illegible]

[illegible] the surrounding [illegible]

This data indicates that (1) [illegible]

## B. Water Quality

Research has shown that irrigation increases salinity of streams in two ways. First, a portion of the water diverted from a stream for irrigation is consumed by plants or evaporation. The unused water will be returned to the stream. Assuming soils are flushed to keep salts from accumulating and a proper salt balance is maintained, the return flow will have the same tonnage of salt as the water originally diverted from the stream. However, the concentration of salts will have increased greatly because of the water consumed during irrigation.

Second, the drainage water percolating through the soil mantle and subsurface geologic material will take into solution additional salts which are returned to the stream. This is especially true for soils derived from the Mancos Formation. The EPA (17) found that this salt loading ranged from as low as one-tenth of a ton to as much as 8.5 tons per acre per year. Figure 9 shows the range of salt pickup for irrigated areas in the Colorado River. This salt pickup not only increases the salt concentration of water but adds to the total annual salt load.

It is very difficult to separate salinity from irrigation and natural sources because of the intermingled ownership pattern along streams. The EPA developed data will be used to separate these salt contributions.

The concentration of salts in streams coming from NRL varies significantly. It was found that concentration of salts in streams originating from groundwater on NRL ranged from approximately 3,000 to 5,000 mg/l. Concentration of salts in surface water, however, ranged from 500 to 2,000 mg/l, see BLM open fill report previously cited.

Low flow originating on NRL is primarily from underground sources such as springs, seeps, and subsurface channel flow which may surface at some point in the channel. The discharge rate is low, E.C. (salinity) is relatively high, and the water is clear. The water from underground sources contains significantly higher sodium content than surface water. Underground sources of sodium (salt) in Marine shales are nearly unlimited.

Low flow often produces evaporites (salt deposits) along stream channels because of the high salt content and water consumption by evapotranspiration. High flow (surface water), although lower in E.C. carries a large volume of salt (tons of salt) as compared to the low flow (lower volume). High flow also flushes salt evaporite deposits into perennial streams thus raising their salinity.

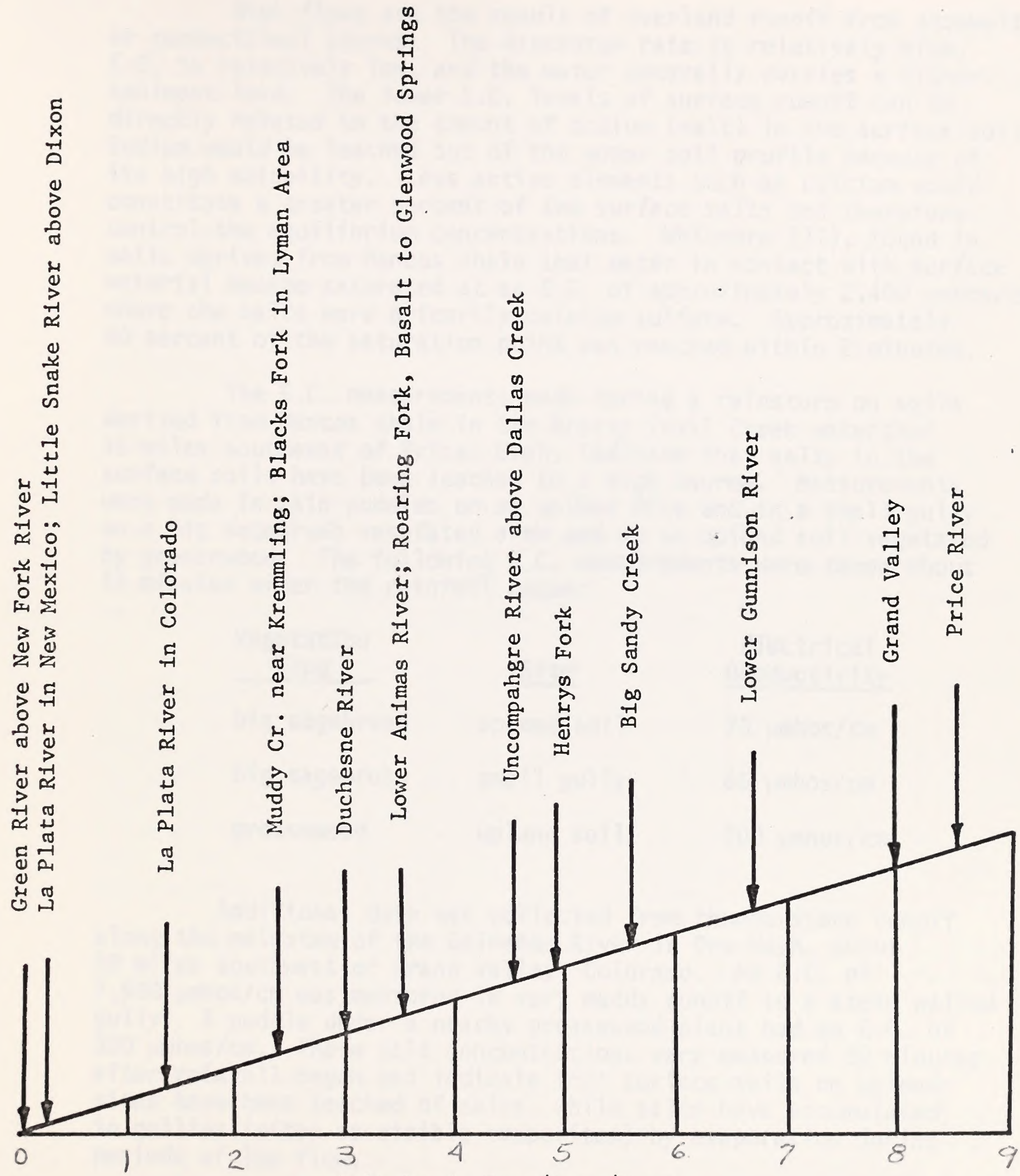



Figure 9. Observed Range of Salt Yields from Irrigated Areas in the Upper Colorado River Basin

Adapted from "The Mineral Quality Problems in the Colorado River Basin," Appendix A, Environmental Protection Agency, 1971.

High flows are the result of overland runoff from snowmelt or convectional storms. The discharge rate is relatively high, E.C. is relatively low, and the water generally carries a higher sediment load. The lower E.C. levels of surface runoff can be directly related to the amount of sodium (salt) in the surface soil. Sodium would be leached out of the upper soil profile because of its high solubility. Less active elements such as calcium would constitute a greater percent of the surface salts and therefore control the equilibrium concentrations. Whitmore (71), found in soils derived from Mancos shale that water in contact with surface material became saturated at an E.C. of approximately 2,400 μmhos/cm where the salts were primarily calcium sulfate. Approximately 80 percent of the saturation point was reached within 2 minutes.

The E.C. measurements made during a rainstorm on soils derived from Mancos shale in the Grassy Trail Creek watershed 16 miles southeast of Price, Utah, indicate that salts in the surface soils have been leached to a high degree. Measurements were made in rain puddles on an upland site and in a small gully on a big sagebrush vegetated area and on an upland soil vegetated by greasewood. The following E.C. measurements were taken about 15 minutes after the rainfall began:

| Vegetation Type | Site | Electrical Conductivity |
|---|---|---|
| big sagebrush | upland soil | 73 μmhos/cm |
| big sagebrush | small gully | 66 μmhos/cm |
| greasewood | upland soil | 200 μmhos/cm |

Additional data was collected from thunderstorm runoff along the mainstem of the Colorado River in Dry Wash, about 10 miles southwest of Grand Valley, Colorado. An E.C. of 1,930 μmhos/cm was measured in very muddy runoff in a steep walled gully. A puddle under a nearby greasewood plant had an E.C. of 330 μmhos/cm. These salt concentrations were measured 30 minutes after rainfall began and indicate that surface soils on upland sites have been leached of salts, while salts have accumulated in gullies (often as visible evaporites) by evaporation during periods of low flow.

The E.C. was also measured in spring runoff water stored in ponds, from grass and sagebrush vegetated watersheds located at Boco Mountain. Little difference in E.C. was found, ranging from 210 to 300 μmhos/cm. However, the grass watersheds both yielded slightly less salt than the comparison sagebrush watersheds. This difference may be an indication of increased leaching of salts in the soil surface, since Shown et al (61), indicated that the grass watersheds had a greater volume of spring runoff from snowmelt than the sagebrush watersheds. Measurements were also made of thunderstorm runoff stored in collection ponds at Badger Wash. The E.C. was 1980 and 1600 μmhos/cm from Badger Wash Detention Dam and West Twin, respectively. This difference is probably due to watershed soil differences and a greater amount of channel flow above the Detention Dam.

High flows carrying a large volume of sediment can contribute salt to large streams in excess of the salt carried in solution. Salt in the sediment, while not being dissolved in saturated water of small streams, will be dissolved when the sediment is discharged into larger streams with better quality water. Sediment transported salt is the subject of several current BLM funded research projects. It is hoped that results of this research can help quantify salt transported in sediment.

Upland erosion is a source of salinity when soil below the leached surface inch or less is carried into streams and soil particles containing salt are brought into contact with water. Stream bank erosion is also an important source of salt contributing sediment from deeper in the soil profile. Peak flows from poor condition lands discharge large quantities of silt into the Colorado River and its tributaries. The cutting force of high peak flows coming from poor condition rangelands is formidable and may exceed anything thought of as being a natural process.

In all salinity measurements taken thus far, water leaving national forest lands has varied from an E.C. of 30 to 700 μmhos/cm, with much of the water falling in a range of 300 to 500 μmhos/cm. This is also true for water coming from NRL high country with geology similar to national forest lands. Water crossing NRL foothills covered by pinyon-juniper and big sagebrush has also been within an E.C. range not exceeding 900 μmhos/cm. Low elevation NRL produce water with an E.C. range from 600 to 2400 μmhos/cm. These lands are generally found on high salinity producing geologic formations, supporting salt desert shrub vegetation (greasewood, shadscale saltbush, nuttall saltbush, and mat saltbush).

Irrigation return flows from cropland and in low valleys produce water with an E.C. range from 600 to 5800 μmhos/cm. The E.C. figures for water from all sources vary depending upon

the quality of water entering the class of land (BR) being monitored, i.e., water quality of NRL low lands, may be higher if water coming from national forest high country has a high E.C., or vice versa. Water quality monitored farther downstream through cropland deteriorated markedly, indicating water reuse and significant salt pickup as found by EPA (17).

Measurements taken thus far graphically illustrate why data taken at a single point cannot be used to explain sources of salinity over a general area above a gaging station. The following data taken on a short reach of Huntington Creek in Utah show the magnitude of variability that can occur in a stream over a short distance. The data indicate an apparent increase in salinity of 490 μmhos/cm over a distance of 1.2 miles and then an almost equal decrease of 430 μmhos/cm over a distance of 0.9 miles. Surface geology is a rather complex mix of twisted and tilted formations or strata. No visible surface water was seen to enter Huntington Creek within this distance. However, subsurface saline geologic material or a deeper saline aquifer could cause the increase in salinity of Huntington Creek near the Rilda Canyon Road and a high quality aquifer may be the diluting factor further down the stream. It is also possible that the coal mine near the Rilda Canyon Road is resulting in a saline seepage into Huntington Creek.

Huntington Creek was able to nearly maintain the E.C. level over a distance of 1.3 miles just above the Utah Power & Light plant (E.C. 1000 to 1060 μmhos/cm), even though the creek passed through a region of rolling hills vegetated by pinyon-juniper and big sagebrush. The E.C. measured below the power plant and tract of irrigated farmland showed an increase of 750 μmhos/cm over a distance of 3.0 miles. Very little, if any, surface water has entered Huntington Creek over this distance. The increase in E.C. may be caused by the power plant, irrigation return flow, saline geology or deep aquifers.

C. <u>Grazing</u>

Present grazing on NRL within the Upper Colorado River Basin is moderate to heavy. Examples of heavy grazing can be found at high elevations on summer pastures, in the juniper-pinyon zone, and at the lower elevation salt desert shrub zone where winter grazing is common.

the quality of water entering the [illegible] (1980) being monitored [illegible] may be higher if water [illegible] E.C.s [illegible] or elsewhere. [illegible] further downstream [illegible] indicating water table [illegible] as found by [illegible] (1979).

[illegible] illustrates why [illegible] sources of [illegible]. The following data [illegible] show the magnitude of variability that can occur in a stream over a short distance. The data indicates an apparent increase in salinity of [illegible] over a distance of 1.2 miles and then an almost equal decrease [illegible] over a distance of 0.3 miles. Surface [illegible]. No [illegible] water was seen [illegible] Creek within [illegible]. However, subsurface [illegible] could cause the increase in salinity [illegible] Road and a high [illegible] further down the stream. [illegible] near the [illegible] Road is [illegible] into [illegible] Creek.

[illegible] Creek [illegible] E.C. level over a distance of [illegible] miles just above the [illegible] Light plant [illegible]. The E.C. [illegible] below the power plant [illegible] increase of 750 [illegible]. The increase in E.C. may be [illegible] power plant [illegible] saline seepage [illegible] aquifers.

C. [illegible]

[illegible] quality [illegible] within the upper [illegible] River Basin [illegible]. Seepage can be found at high elevation [illegible] and at the lower elevation [illegible] where [illegible] is common.

## D. Estimated Economic Benefits of Salinity Control

In 1965, the BLM, together with the BR and the Range Science Department, USU, undertook a five year cooperative study of erosion control efforts of the Mancos shale badlands (frail lands) near Cisco, Utah. During the period from about 1955 through 1967, the BLM and the BR cooperated in the construction of over 25,000 check dams, or "gully plugs" and 5,000 acres of contour furrows for the purpose of reducing sediment yield. The primary concern for the frail lands was that while they only contribute 5 percent of the water flowing past Lee Ferry, Arizona, they contribute nearly 44 percent of the sediment load deposited into Lake Powell.

Workman and Keith (74) compared minimum project costs with maximum project benefits from erosion control practices applied to the Cisco, Utah watershed. They concluded that treatment of frail lands for the single purpose of sediment control was economically unsound.

The benefits included in the study covered only: (a) the present value of water treatment costs avoided, and (b) the present value of extending the life of Glen Canyon Dam into perpetuity. Salinity reduction benefits identified in studies conducted by the EPA (18), Kleinman and Brown (41) for the BR, and Valentine (64) have been added to the benefits already identified in the Workman and Keith Watershed Study on the assumption that there is a positive correlation between sediment production and salinity.

Table 10 summarizes the annual agricultural, municipal, and industrial benefits estimated by EPA, BUREC, and Valentine.

Table 10. Estimated Annual M&I and Agricultural Benefits from Reducing Salinity at Imperial Dam, California

| | $/Mg/l at Imperial Dam | | |
|---|---|---|---|
| | Environmental Protection Agency | Bureau of Reclamation | Valentine |
| Municipal & Industrial | $ 9,142 | $121,000 | $125,800 |
| Agriculture | $45,900 | $108,400 | $129,300 |
| Total | $55,042 | $229,400 | $255,100 |

Sufficient information is not available to specify the relationship between the actions taken in the Cisco sediment control study and reductions in salinity at Imperial Dam. However, by comparing the costs associated with the Cisco sediment control practices with the sediment related benefits, plus benefits associated with hypothesized reductions in salinity, we can identify the relationship that would have to hold between these practices and salinity reduction in order for the practices to be economically feasible.

Workman and Keith (74) estimated the Cisco watershed would yield an average of 484,000 tons of salt per year from natural sources. This results in an estimated contribution of salinity at Imperial Dam of 36 mg/l. Table 11 presents benefit/cost estimates that could be expected if alternative hypothesized reductions in salinity were attained by treatments carried out on the Cisco area. Based on results of the EPA study, in order for practices of the type employed in the Cisco study to be feasible, a reduction in salinity of 50 percent would have to be attained. The Kleinman & Brown (41) and Valentine (64) benefits estimates indicate feasibility could be attained with salinity reductions of only 10 to 25 percent.

Table 11. Estimated Benefits from Reducing Salinity (Low Cost - $5.45/acres for 50 years)

| Scenarios | $ Salt Reduction | Salt Reduced (Mg/liter) | Benefit-Cost Ration | | |
|---|---|---|---|---|---|
| | | | EPA | BR | Valentine |
| 1 | 100% | 36 | 2.1:1 | 8.4:1 | 9.4:1 |
| 2 | 50% | 18 | 1.0:1 | 2.4:1 | 4.7:1 |
| 3 | 25% | 9 | .51:1 | 2.1:1 | 2.3:1 |
| 4 | 10% | 4 | .20:1 | .84:1 | .94:1 |
| 5 | 05% | 2 | .10:1 | .42:1 | .47:1 |

Even though we presently do not know whether the relationship between sediment reducing practices and salinity is sufficient to ensure that feasible solutions can be devised, the potential seems great enough to warrant further investigation. Studies presently underway will determine how effective these practices actually are at reducing salinity.

## VII. ALTERNATIVE CORRECTIVE MEASURES

In the past the BLM has used a variety of treatments for erosion control. The results of research into the usefulness of each of these corrective measures is discussed. Salinity was generally not a concern of these researchers. However, this report has attempted to project possible effects upon salinity based on reduced sediment loss, changes in volume of runoff, and increased vegetation cover as reported. Research projects now underway and funded by the BLM, EPA, BR and others are designed to answer critically important questions concerning mechanisms involved in salt pickup and transport from the salt source to the Colorado River and the effectiveness of treatments in controlling salinity. Answers to these questions will affect the kinds of corrective measures which would be technically feasible. A search of the literature has found research results which give some answers and indicate possible strong and weak points of presently accepted watershed stabilization practices. For purposes of this interim report, current practices will be evaluated on their possible usefulness in reducing salinity from NRL based on analysis of available knowledge.

Since the major salinity transport mechanism is water moving from the area, salinity control measures must be designed to change the hydrologic characteristics of the watershed so as to reduce this water movement. This section discusses common watershed practices and assesses their effectiveness in changing hydrologic characteristics.

### A. Juniper-Pinyon Eradication

For many years eradication of juniper-pinyon stands has taken place on many acres for purposes of increasing livestock and wildlife forage and improving watershed conditions. The justification has been that grass can protect the soil from erosion better than trees and shrubs. However, Gifford (26) found that after five years there was no difference in water or sediment yield between chained juniper-pinyon sites and adjacent woodland controls in Utah. He also found that where trees were chained and windrowed and the areas seeded to grass, water and sediment yields increased over yields measured on adjacent native juniper-pinyon woodland stands. This occurred even though ground cover as made up by grass, forbs, and litter was higher on the chained, windrowed and seeded sites. Gifford and Shaw (31) found that "vegetation densities as measured in this study had no measurable effect on soil moisture patterns." Soil moisture did increase on the debris-in-place chained sites but "there was no indication of any excess moisture for eventual deep seepage."

Williams et al, (73) and Gifford et al, (32) found that there were no significant differences in infiltration rates or sediment yields on chained and seeded areas as compared with adjacent native woodland areas. Gifford (29) indicates that the juniper-pinyon woodland provides a good watershed cover, one not usually improved upon by eradication of the trees and conversion to grass. He states that "if you are trying to manipulate the pinyon-juniper type, your goal, from a hydrologic standpoint, ought to be to get back to where you started initially." These findings tend to discourage use of the practice of juniper-pinyon chaining for strictly hydrology manipulation purposes.

B. Big Sagebrush Eradication

The big sagebrush community has been treated much the same as the juniper-pinyon woodland. It has been a common practice to spray or burn big sagebrush in order to release remnant native grasses in the stand and thereby convert the site to a grassland. Where remnant grasses are too few, the area is plowed to kill sagebrush and grasses are planted. The desired result is a site producing several times more forage for livestock and also, supposedly, yielding clear water and less sediment.

Not until recently has anyone challenged the thesis that sagebrush does not protect the soil against sediment loss as well as grass. Shown et al, (61) found on Boco Mountain that evaporation from the soil surface was greater from big sagebrush stands (46 percent bare ground) than from the grass stands (31 percent bare ground). Runoff during the growing season did not vary between sites.

Gifford and Busby (30) found that plowing of big sagebrush in Idaho reduced infiltration and increased soil loss the first year after treatment. Gifford (25) had earlier found that rate of infiltration was lower and sediment loss greater one year after sagebrush was removed. However, he found that there was no significant difference in infiltration rates and sediment yields between the cleared and natural big sagebrush stand after the first year, even though percent ground cover on the cleared and seeded site was greater the second year than on the untreated site. Blackburn and Skau (5) found no significant differences in infiltration rates and sediment yields between plowed and seeded sites and untreated big sagebrush stands.

Rosa and Tigerman (56) analyzing data from several sites covering a period of years from 1941-47 found that sediment yield in big sagebrush stands was directly correlated with range condition of the site. Range condition is an indicator of the number and

variety of species of plants found on a site with reference to what would be found if the area was protected from grazing. Good condition range would have a good mixture of grasses, forbs and other shrubs mixed with the big sagebrush plants. Poor condition range would have a very few species of understory plants mixed with big sagebrush. Rosa and Tigerman (56) found that poor condition (range) sagebrush sites produced three times more sediment than good condition sagebrush sites. The research results reported above indicate that conversion from native stands of big sagebrush to seeded grass does not significantly improve infiltration rates or reduce loss of sediment.

It appears, then, that eradication of sagebrush is not an effective means of influencing hydrologic characteristic and, therefore, would be of limited effect in controlling salinity.

### C. Ripping, Pitting, and Contour Furrowing

Mechanical treatments have been applied on NRL to artificially break up a compacted soil crust, increase infiltration, pond water on site, and reduce runoff and sediment loss. Work has been attempted on a variety of sites having different soil characteristics, slope, vegetation types, and climate. Ripping has proved to be the least successful of this kind of practice. Frevert et al, (21) indicate that ripping has not greatly improved soil conditions. Observations by BLM managers have revealed that in fine-textured soils (clay, clay loam) attempts to open the soil to improve infiltration have failed because soil particles wash into the ripped trench and seal it over after the first year.

Barnes et al, (2) found that pitting increased forage production but that the life of pits may not extend much beyond 10 years. Branson et al, (7) found that after an eight year period pits were no longer visible but that grasses seeded during the pitting operation were still alive. They also stated that their studies indicate pitting "is of questionable value as a land-treatment practice." This was based primarily on the failure of forage production to increase over untreated sites. However, even ignoring forage production, the fact that pits are easily obliterated makes them a questionable treatment for reducing salinity.

In contrast to the findings on ripping and pitting, Wight and Siddoway (72) reported that contour furrowing increased soil water content 43 percent over nonfurrowed plots over a 3 year period on 7 dates tested. These dates coincide with periods following snowmelt or high rainfall.

The BLM has had success in reducing runoff and sediment yields by constructing contour furrows on upland portions of watersheds on a variety of soils including soils derived from the Mancos Formation in the Vernal and Price, Utah, and Grand Junction, Colorado areas.

variety of species of plants based on a site with reference to what would be found if the area was protected from grazing. Good condition range would have a good mixture of grasses, forbs and other shrubs mixed with the big sagebrush plants. Poor condition range would have a very few species of understory plants mixed with big sagebrush. Hook and Thompson (19) found that poor condition (range) sagebrush sites produced three times more sediment than good condition sagebrush sites. The relatively notable unpublished data indicate that conversion from native stands of big sagebrush to crested wheat does not significantly increase infiltration rates or reduce loss of sediment.

It appears, then, that eradication of sagebrush is not an effective means of influencing hydrologic characteristics and, therefore, would be of limited effect in controlling salinity.

C. Ripping, Pitting, and Contour Furrowing

Mechanical treatments have been applied on BLM land to artificially break up a compacted soil crust, increase infiltration, store water on site, and reduce runoff and sediment loss. Work has been attempted on a variety of sites having different soil characteristics, slope, vegetation types, and climate. Ripping has proved to be the least successful of this kind of practice. Branson et al. (17) indicate that ripping has not greatly improved soil conditions. Observations by BLM personnel have indicated that, in fine-textured soils (clay, clay loam) attempts to open the soil to improve infiltration have failed because soil particles wash into the ripped trench and seal it over after the first rain.

Barney et al. (17) found that pitting increased forage production but that the life of pits was not extended much beyond 10 years. Branson et al. (17) found that after an eight year period pits were no longer visible but that grasses seeded during the pitting operation were still alive. They also stated that their [illegible] pitting is of questionable value as a range treatment practice. This was based primarily on the failure of [illegible] to increase grass on barren sites. However, even [illegible] forage production, the fact that pits are mostly obliterated [illegible] make a questionable treatment for reducing salinity.

In contrast to the findings on ripping and pitting, Wight and Siddoway (17) reported that contour furrowing increased soil water content 15 percent over nonfurrowed plots over a 3 year period on 7 sites tested. Their study compares with pitted sites probably of high rainfall.

The BLM has had success in reducing runoff and sediment yields by constructing contour furrows on upland rangelands of which there are a variety of soils including soils derived from the formations of the Mancos and Green River, Uinta, and Wasatch formations.

Branson (6) states that contour furrows were the most effective treatment tested for retaining water on site, removing salt from its effect on plants through leaching (increased soil moisture available to plants), increasing plant yields, and reducing salt content of runoff. A significant consideration is the cost of contour furrowing; however, a reappraisal of the Cisco study data is proposed for FY 1977 and the results of including desalting benefits may make contour furrowing more economically feasible.

D. Water Spreading, Gully Plugs, Small Reservoirs

Gifford (25) reporting on work by several authors states that water spreader dikes should cover an area large enough so that exceptionally large flows will not overtop dikes. Most of the sediment will settle on the upper 20 percent of the system. Spreader dikes should be constructed on areas having a slope no greater than two to five percent. Spreader dike systems should not be constructed as a control measure for stopping sediment from badland areas from moving downstream.

Miller et al, (48) state that spreader dikes are most useful in medium to fine-textured soils. They found in flooded areas on fine textured soils that salt levels were lower in the A horizon and higher in the $B_2$ and $B_3$ horizons. Whether ot not salt levels would build up in the lower soil horizons enough to harm plant growth was not stated but the report infers that the authors believed salinity was not a factor in selecting potential spreader systems obviously designed for forage production rather than flood control.

Water spreader dikes could conceivably be designed for sediment and salinity control. However, sites with physical characteristics suitable for spreader dikes are limited. Also, spreader dikes are expensive to design, build, and maintain.

Gully plugs have been constructed by the BLM as a means of stopping movement of sediment and stabilizing gullies. Small reservoirs have been constructed for livestock water but they also trap sediment suspended in the water. Gifford (25) cites studies which show that earth-fill structures are susceptible to failure if construction does not follow rigid specifications. In one instance where gully plugs were constructed in central Utah, storage reservoirs for silt were filled in 10 years and little storage capacity remained.

However, Lusby and Hadley (44) found that after reservoirs behind dams were filled with sediment, deposition of sediment continued upslope in the gully channel. At Sheep Creek in southeastern Utah, 47 percent of the silt deposited behind the dam is

above the elevation of the spillway and the deposition of silt is continuing. The slope of deposited sediment is 30 to 60 percent of the original streambed gradient. This means that the stability of sediment in the gully (ability to stay in place) depends upon the dam, which caused the original deposition, continuing to reduce velocity of flood water below that necessary to cause channel cutting. Vegetation established on the new sediment in the gully will also help reduce the velocity of water. The gully plug must also effectively stop underground flow. If water cuts under the dam, underground flow will cause a loss of sediment through piping, one of the first stages of gully erosion.

Gully plugs may not completely stop the movement of salts in water moving downstream even though sediment remains trapped behind dams and in gullies upstream. Salt trapped in sediment may be leached into shallow groundwater beneath the drainage channel and surface again below the gully plug. A similar situation was recorded by the Geological Survey in work on Badger Wash, Colorado (66) and is strongly reflected in data gathered by the SCS in Grand Valley, Colorado, which shows lower salt contents in sediment behind dams than occur on upland sites, Elkin (16).

E. Detention Dams

The BLM has constructed many detention dams for erosion control. Costs of moving dirt, compacting soil, and shaping the dike for detention dams are comparable with those needed to construct spreader dikes. However, there is an additional cost of constructing a spillway, which may be more expensive than the dam.

Detention dams fulfill the same purpose as gully plugs, they stop sediment in a reservoir behind the dam and when this is filled, sediment aggrades upstream in the gully channel. Hadley (33) found that sediment in gullies behind dams reduced the channel gradient and that eight percent of the deposition was above the spillway level. This is similar to work reported by Lusby and Hadley (44) on smaller areas except amount of sediment is smaller. This agrees with the statement by Hadley (33) that "in similar drainage basins the sediment yield decreases with increase in size of drainage area." Detention dams are larger and have a more complex spillway system and should withstand heavy flooding better. As with gully plugs, salt trapped behind detention dams is subject to leaching by flood water trapped with the salt laden sediment, Elkin (16). One solution to this problem would be to seal the bottom of the reservoir behind the detention dam, at additional cost. However, this may not stop leaching of salt in sediment deposited in the aggrading gully channel upstream.

F. Selective Withdrawal

Water quality of streams can be improved by selectively withdrawing the base or low flows with high salt concentrations and

bypass good quality high flow water. The base flow is diverted to an evaporation pond for total consumption. The evaporation ponds must be sealed or lined so that seepage does not return saline water to the stream through the ground water. Ponds must also be protected from surface runoff which would cause overtopping and spilling the concentrated brines back into the stream system.

G. Control of Livestock Grazing

Gifford (28) states that "There is little doubt that grazing has an impact on hydrologic behavior of rangeland. . . . magnitude and duration of that impact is a reflection of the intensity and management of the grazing activity." Smeins (62) states that trampling by livestock "can disturb the soil surface, cause compaction and destroy not only aboveground but also underground portions of plants. Through time this can reduce the amount and vigor of the vegetation and increase potential for runoff and erosion." Rhodes et al, (55) found after 20 years of grazing that infiltration rate was inversely proportional to grazing intensity. They also found that bulk density of the soil was greater on grazed sites to a depth of three feet than on nongrazed sites. The heavy stocking rate had the highest soil bulk density of all treatments. Rauzi and Smith (54) found infiltration rates on a sandy loam during the first 15 minutes of simulated rainfall were significantly higher on lightly and moderately grazed pastures than for the heavily grazed pasture. Infiltration increased slightly after 25 minutes on the lightly and moderately grazed pastures but continued to decrease on the heavily grazed pasture.

Schumm and Lusby (59) observed several aspects of soil characteristics as affected by season on steep to moderately steep slopes with soils derived from the Mancos Formation in western Colorado. Crown cover of living plants was 8 to 15 percent. They found that as a result of frost the soil surface was loosened, forming an aggregate material which is friable and highly permeable, see Figure 10. All trace of rills formed by erosion during summer thundershowers was obliterated. However, during the summer rainfall the edges of the aggregates were destroyed as fine soil particles were washed into interspaces between the aggregates, partly closing them. A crust also formed on the outer surface of the aggregates. Infiltration is maximum during the spring and decreases as summer progresses. They found that fall runoff greatly exceeded spring runoff. The ratio of runoff to rainfall on hill slopes also increased from spring to fall.

Lusby (42) reported that during the period from 1954-61 average runoff from grazed watersheds was 20 percent greater than from ungrazed watersheds. At the same time sediment yield from

Figure 10. Typical Open Soil Formed in Mancos Shale Following Winter Frost Heaving.

from ungrazed watersheds was 18 to 54 percent less. During the study period no significant changes in vegetative cover had occurred. He theorized that trampling by grazing animals during the winter and spring compacted soils derived from the Mancos Formation that would normally be loose and friable as a result of winter frost heaving. Compacting therefore reduced infiltration. Trampling was listed as a cause of increased bare soil on grazed areas by Branson and Owen (9).

Lusby (43) reported on additional data collected by the same study through 1966 and integrated with previously collected data. He states that runoff in the hilly Mancos shale area at Badger Wash "occurs almost wholly in response to summer rains." He found that gullies draining grazed watersheds had nearly twice as much erosion as those from ungrazed watersheds. Grazed watersheds produced 30 percent more runoff and 45 percent more sediment than ungrazed watersheds. Maximum reduction in sediment load occurred after three years of exclusion from grazing. At the beginning of the study no significant differences in vegetative cover were measured across the watersheds. At the end of the study, shrub cover, litter and moss cover was lower and bare ground was higher on grazed watersheds. Several dry years had been recorded but this did not cause a similar deterioration in vegetation on the ungrazed watersheds.

Schumm and Lusby (59) state that in the Mancos Formation, both the bedrock and soils are saline. For this reason, any reduction in sediment yields will reduce salinity in the Colorado River.

The research findings listed above point out that heavy grazing increases sediment yield. Much of the geology underlying NRL in the Upper Colorado River Basin contains some level of salt, SCS (63).

On soils derived from the Mancos Formation with a high salt content and relatively low percent ground cover of vegetation, effects of trampling are intolerable. Figure 11 shows how hoof prints of cattle compact soil and destroy soil aggregates in frost heaved soil derived from the Mancos Formation. Grazing during winter and spring when the area is normally grazed because of open suitable weather is most harmful according to Lusby (43). Grazing during summer may not be possible because of effects of high temperatures on livestock and lack of water. However, summer grazing would also result in additional compaction of soil and increase sediment loss. Lusby (43) states that complete removal of livestock can reduce sediment yields by 45 percent within 3 years after grazing ceases. Figure 12 shows rills and gullies forming on a Mancos hillside with a good cover of shadscale and mat saltbush.

Observations made for this study during the spring and summer indicate that grazing in excess of the moderate level is widespread throughout Colorado and Utah within the Upper Colorado River

Figure 11. Livestock Hoof Prints in Soil Derived from the Mancos Formation.

Figure 12. Rills and Gullies on Mancos Hillside with Good Vegetative Cover.

Basin (no observations were made in Wyoming). This includes private and state owned grazing lands as well as NRL. Compaction of soil by livestock trampling (excessive number of animal tracks), close utilization of forage plants, and large number of livestock droppings were all observed.

Grazing by domestic livestock as a use of the land needs to be reevaluated as to its effects upon loss of sediment from soils containing salts.

## VIII. CONCLUSIONS

Research and BLM investigations indicate that two probable sources of salinity from NRL are:

A. Salinity from underground sources.

1. Saline aquifers which enter stream channels as diffuse sources along unknown reaches of streams or at more confined points such as fault zones.

2. Saline springs and seeps.

B. Salinity from overland flow.

1. Salts leached from the soil surface during periods of runoff.

2. Salinity from sediment transported to stream channels.

3. High flow runoff which takes into solution salts stored in sediment and as evaporites in ephemeral channels.

4. Salts taken into solution by perennial streams as they cross salt bearing geologic outcrops or soils.

Saline geologic formations are shown in Figure 2. Residual soils have been classified into nonsaline, slightly saline, moderately saline and strongly saline as shown in Figure 3. The upper limit of salt concentration designated for nonsaline soils was too high, 4,000 μmhos/cm, causing soils which can produce large quantities of salt to be included in the nonsaline class. At present, 78 percent of the Upper Basin is classed as nonsaline. The extent of lands within the nonsaline class yielding salts is unknown. Soil surveys now being conducted by the SCS, for the BLM, should collect salinity data to a level sufficient to develop an improved map of saline soils.

An effective salinity control program for an area must identify the salt transport mechanism and apply treatments that will effectively reduce or control salt movement. Surface movement of salt is expected to be the major factor to control -- not because it is the major contributor but becaue it is easier to control. Underground flows very likely contribute more salt to the river but, to date, the locations where aquifers enter streams are unknown. Measures required to block saline underground waters from entering the river system have not been developed.

Contour furrowing may be the most effective mechanical tool for reducing salinity from overland flow. Trampling by grazing

animals may have harmful effects on furrows which reduce their useful life. However, research is needed to determine how extensive these effects are and what additional influence soil type, topography, weather, and intensity of grazing have.

Grazing by livestock needs to be reevaluated as to its effects upon loss of sediment in soils containing salts. Elimination of livestock grazing may be the most effective control of salinity on the frail soils derived from Mancos and other marine shales. Grazing management can be an important tool for use on areas where vegetative cover is, or can potentially be, present in sufficient quantity (greater than 20 percent ground cover) to provide protection to the soil.

Detention dams on large drainages, or dikes across small gullies (to form sediment reservoirs) may be useful to trap salt laden sediment. The bottoms of sediment reservoirs must be sealed, so that salts will not leach into the shallow ground water and move downstream. Dams may be useful where steep topography makes on-site treatments, such as contour furrows, impractical. They may also be useful in reducing geologic loss of sediment. However, location of suitable sites is difficult in areas where topography is rough, stream channel gradient is steep, or soils are shallow.

Large areas within national parks and monuments such as Bryce Canyon, Cedar Breaks, Zion, Capital Reef, Arches and Rainbow Bridge have high geologic erosion rates and produce salt in some quantity. The BLM administers large areas with similar topography and erosion potential. The SCS (63) states that "treatments of high sediment yields from natural geologic areas is practically impossible." They also mention that while management and treatment practices could affect large areas of forest and rangeland, salt reductions from these diffuse sources would be small, "usually less than three percent of the total yield."

There may be legal problems associated with implementation of salinity control measures, depending upon the amount of water they will consume. The Upper Basin states have taken the stand that water consumption for salinity control is not a recognized beneficial use. Most of the water will be consumed in the Upper Basin while the benefits will be derived in the Lower Basin. Under existing compacts and legal constraints, it is required that consumed water be deducted from allocations to the state where the water is consumed. This penalty assessed against salinity control measures taken in the Upper Basin is a problem not addressed by this study. However, it may affect the ability of the BLM to implement a viable program and should be considered.

## IX. RECOMMENDATIONS

The following recommendations are made for continuation of the Colorado River salinity study. This report specifically recommends that:

A. The BLM continue the salinity study during FY 1977 in order to:

1. Obtain results of on-going BLM funded research along with results of outside research, and incorporate these into analysis of technically feasible treatments.

2. Collect and analyze the necessary economic data needed to determine costs and benefits of salinity control measures.

B. The BLM salinity study concentrate data collection, analysis of treatments and economic analysis on a single drainage basin having significant quantities of saline geologic formations and/or soils on NRL. The Price River drainage, as outlined in Public Law 93-320, may prove to be a good selection. The study would be directed toward analysis of the effectiveness of existing treatments and management practices in reducing salinity, determination of costs to implement control practices, and an evaluation of benefits derived. Results obtained here would be extrapolated to other NRL having similar characteristics, within the Upper Basin.

C. Additional areas outlined in Public Law 93-320 be scheduled for investigation during FY 1978 and succeeding years. Studies would be made on natural lands within these drainage basins to coincide with work being conducted by BR, SCS and EPA on perennial streams and irrigated lands. This would provide a well coordinated analysis of salinity problems and possible controls.

D. BLM establish a water quality data collection network to obtain data from the project drainage basin and from other watersheds where information concerning salinity on NRL is needed. A network would need to be coordinated with the BR, EPA, and SCS programs. The GS could provide assistance in setting up collection stations and gathering data. Water quality data is lacking on smaller tributaries draining NRL. This data is necessary for BLM to accurately quantify salt yielded from arid and semiarid NRL.

E. The BLM, through the salinity study, coordinate salinity control activities with other agencies and groups, including the Bureau of Reclamation (BR), Environmental Protection Agency (EPA), Soil Conservation Service (SCS), and Geological Survey (GS), to prevent duplication of effort. Data and results obtained would also be made available for use by all interested parties.

F. BLM develop a salinity control program to be implemented upon completion of the salinity study. This would include application of treatments found to be feasible.

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